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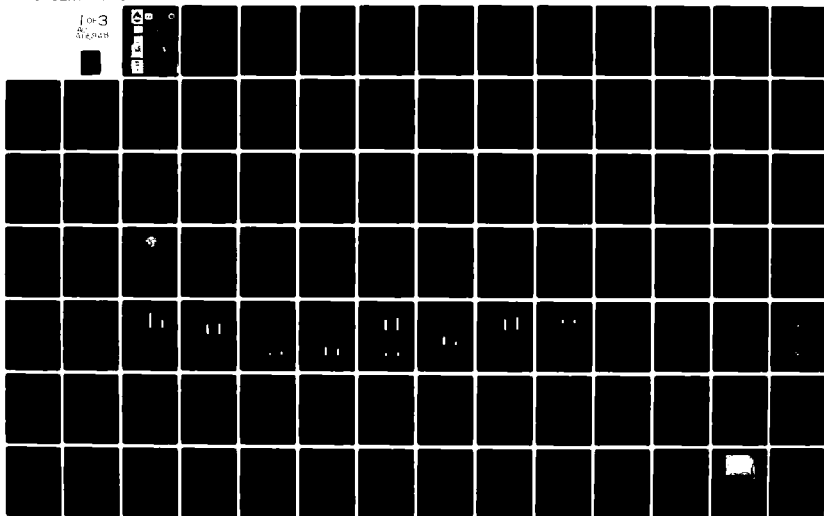
ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/O 6/6  
PROCEEDINGS 16TH ANNUAL MEETING, AQUATIC PLANT CONTROL RESEARCH--ETC(U)  
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MISCELLANEOUS PAPER 8-22-8

PROCEEDINGS,  
16TH ANNUAL MEETING  
AQUATIC PLANT CONTROL  
RESEARCH PLANNING AND  
OPERATIONS REVIEW

17-19 NOVEMBER 1981  
ST. PAUL, MINNESOTA

Environmental Laboratory  
U. S. Army Engineer Waterways Experiment Station  
P. O. Box 631, Vicksburg, Miss. 39180

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June 1982  
Final Report

Approved For Public Release; Distribution Unlimited

Prepared for: Chief, Chief of Engineers, U. S. Army  
Washington, D. C. 20314

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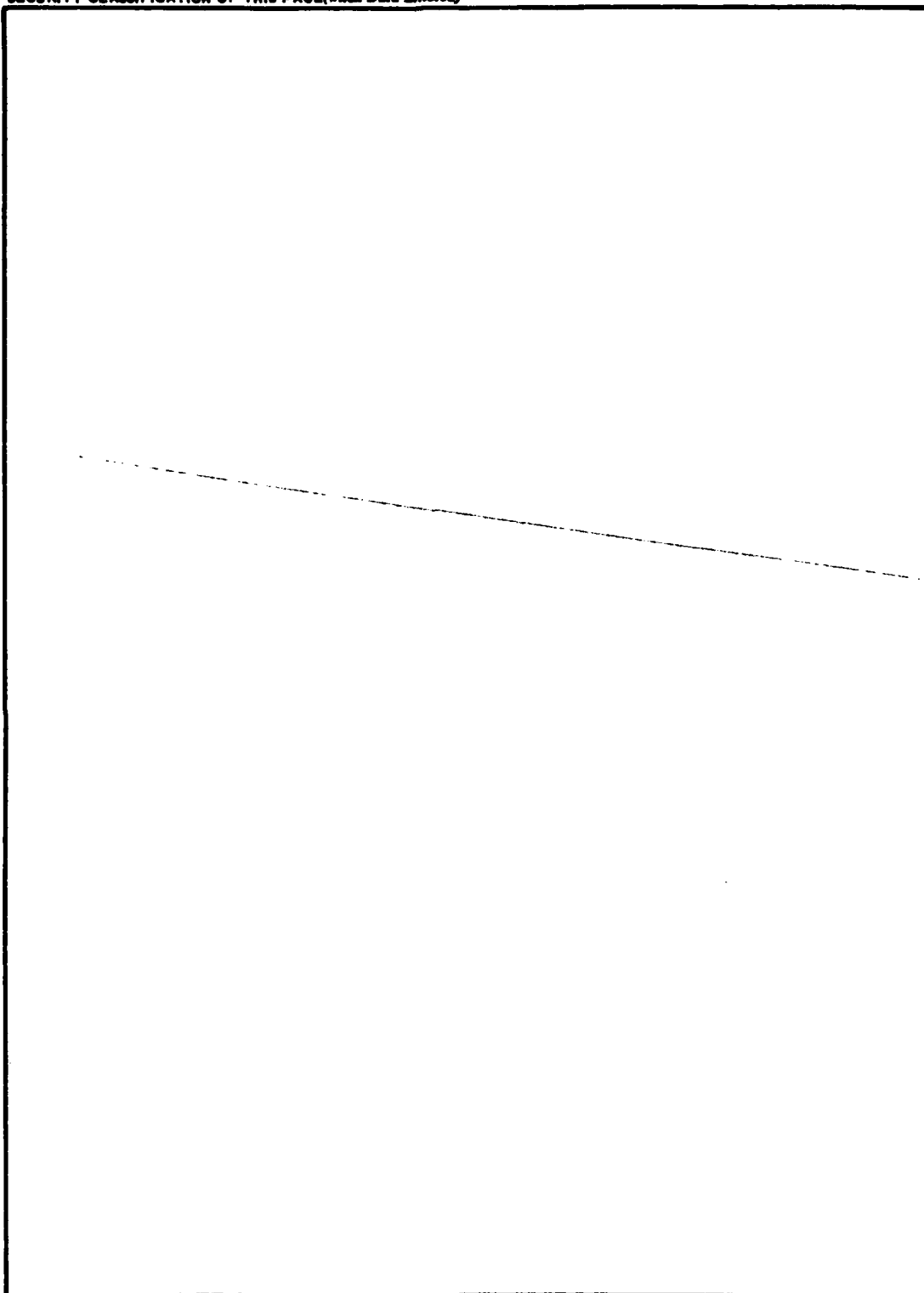
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper A-82-3	2. GOVT ACCESSION NO. AD-A115848	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PROCEEDINGS, 16TH ANNUAL MEETING, AQUATIC PLANT CONTROL RESEARCH PLANNING AND OPERATIONS REVIEW, 17-19 NOVEMBER 1981, ST. PAUL, MINNESOTA	5. TYPE OF REPORT & PERIOD COVERED Final report	
7. AUTHOR(s)	6. PERFORMING ORG. REPORT NUMBER	
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Engineer Waterways Experiment Station Environmental Laboratory P.O. Box 631, Vicksburg, Miss. 39180	8. CONTRACT OR GRANT NUMBER(s)	
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U.S. Army Washington, D.C. 20314	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Aquatic Plant Control Research Program	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	12. REPORT DATE June 1982	
	13. NUMBER OF PAGES 277	
	15. SECURITY CLASS. (of this report) Unclassified	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES  Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Aquatic plant control — Congresses Research planning — Congresses		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  The 16th Annual Meeting of the U.S. Army Corps of Engineers Aquatic Plant Control Research Program was held in St. Paul, Minnesota, on 17-19 November 1981, to review current research activities and to afford an opportunity for presentation of operational needs.		

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## PREFACE

The 16th Annual Meeting of the U.S. Army Corps of Engineers Aquatic Plant Control Program was held in St. Paul, Minnesota, on 17-19 November 1981. The meeting is required by Engineer Regulation (ER) 1130-2-412 paragraph 4c and was organized by personnel of the Aquatic Plant Control Research Program (APCRP), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

The organizational activities were carried out and presentations by WES personnel were prepared under the general supervision of Dr. John Harrison, Chief, EL. Mr. J. Lewis Decell was Program Manager, APCRP. Mr. W. N. Rushing, APCRP, was responsible for planning and chairing the meeting assisted by Mr. Robert L. Lazor.

COL Tilford C. Creel, CE, was Commander and Director of the WES at the time of this meeting and during the preparation of the proceedings report. Mr. F. R. Brown was Technical Director.

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## **AGENDA**

### **16th Annual Meeting U.S. Army Corps of Engineers AQUATIC PLANT CONTROL RESEARCH PLANNING AND OPERATIONS REVIEW**

**St. Paul, Minnesota  
17-19 November 1981**

#### **MONDAY, 16 NOVEMBER 1981**

- 10:00 a.m. Registration—2nd Floor Foyer  
-6:00 p.m.  
6:30 p.m. Reception—Town Square Park (Gardens)

#### **TUESDAY, 17 NOVEMBER 1981 TOWN SQUARE BALLROOM—SECTION 1**

- 8.00 a.m. Registration Continues—2nd Floor Foyer  
8:20 a.m. Call to order and Announcements  
—W.N. Rushing, Waterways Experiment Station (WES)  
8:30 a.m. Welcome  
—COL Tilford C. Creel, Commander and Director, WES  
8:40 a.m. Welcome to the St. Paul District  
—COL William W. Badger, District Engineer, USAE District, St. Paul  
8:50 a.m. Comments on the Research Program—Past and Future  
—J. L. Decell, Manager, Aquatic Plant Control Research  
Program, WES  
9:20 a.m. BREAK  
9:50 a.m. USAE Division/District Presentations—Aquatic Plant Problems  
—Operations Activities  
—Bob Tisdale, Lower Mississippi Valley Division  
—Bob Rawson, Seattle District  
—Joe Joyce, Jacksonville District, APC Ops Support Center  
—Jim McGehee, Jacksonville District  
—Bob Harbaugh, Galveston District  
—Jim Preacher, Charleston District  
—Mike Eubanks, Mobile District  
12:00 noon LUNCH  
1:30 p.m. Mechanical Control Technology Development  
—H. W. West, WES, presiding  
1:45 p.m. Field Test of Aquatic Disposal of Chopped Hydrilla  
—B. M. Sabol, WES

- 1:55 p.m.    Simulation Modeling of Mechanical Control Systems  
—T. D. Hutto, WES
- 2:05 p.m.    Questions
- 2:15 p.m.    Chemical Control Technology Development  
—H. E. Westerdahl, WES, presiding
- 2:30 p.m.    Herbicide Evaluation Program  
—T. K. Van, USDA, Fort Lauderdale, FL
- 2:40 p.m.    Naturally Occurring Growth Regulators for Aquatic Plant Control  
—D. F. Martin, Univ. of South Florida, Tampa, FL
- 2:50 p.m.    Controlled Release (C-R) 2,4-D for Aquatic Plant Control  
—F. W. Harris, Wright State Univ., Dayton, OH
- 3:00 p.m.    Field Evaluation of C-R Formulations at Lake Seminole  
—R. E. Hoeppel, WES
- 3:10 p.m.    2,4-D Label Expansion Project  
—H. E. Westerdahl, WES
- 3:20 p.m.    Questions
- 3:30 p.m.    BREAK
- 4:00 p.m.    Ecology of Aquatic Plant Species  
—J. Barko, WES, presiding
- 4:10 p.m.    Studies on Growth and Spread of Giant Cutgrass  
—R. M. Smart, WES
- 4:20 p.m.    Questions
- 4:30 p.m.    Problem Identification and Assessment of Aquatic Plants  
—B. Payne, WES
- 4:40 p.m.    Questions
- 4:55 p.m.    Adjourn for the day

**WEDNESDAY, 18 NOVEMBER 1981**  
**TOWN SQUARE BALLROOM—SECTION 1**

- 8:30 a.m.    Biological Control Technology Development  
—D. R. Sanders, WES, presiding
- 8:40 a.m.    Investigations of *Paraponyx* spp. for Biocontrol  
—G. R. Buckingham, USDA, Gainesville, FL
- 8:50 a.m.    Distribution and Effects of *Sameodes* on Waterhyacinth  
—T. D. Center, USDA, Fort Lauderdale, FL
- 9:00 a.m.    Overseas Searches for Insects for Control of Aquatic Plants  
—J. Balciunas, USDA, Fort Lauderdale, FL
- 9:10 a.m.    Lytic Enzyme Producing Microorganisms for Eurasian  
Watermilfoil Control  
—H. Gunner, Univ. of Massachusetts, Amherst, MA

- 9:20 a.m. *Fusarium roseum* for Hydrilla Control  
—R. Charudattan, Univ. of Florida, Gainesville, FL
- 9:30 a.m. Biological Control of Waterhyacinths and Alligatorweed in Texas  
—A. Cofrancesco, WES
- 9:40 a.m. Questions
- 9:50 a.m. BREAK
- 10:20 a.m. Assistance Projects of Lake Seminole (Mobile District) and in Texas (Galveston District)  
—J. Leonard, WES\*
- 10:30 a.m. Large Scale Operations Management Test Using Insects and Pathogens in South Louisiana (New Orleans District)  
—E. Theriot, WES
- 10:50 a.m. Questions
- 11:30 a.m. LUNCH
- 1:00 p.m. Large Scale Operations Management Test Using the White Amur at Lake Conway, Florida (Jacksonville District)  
—A. Miller, WES, presiding
- 1:15 p.m. Aquatic Macrophytes of Lake Conway  
—J. Schardt, Florida Department of Natural Resources, Tallahassee, FL
- 1:25 p.m. Fish and Aquatic Mammals of Lake Conway  
—S. Hardin, Florida Game and Fresh Water Fish Commission, Tallahassee, FL
- 1:35 p.m. Herptofauna of Lake Conway  
—S. Godley, Univ. of South Florida, Tampa, FL
- 1:45 p.m. Radiotelemetry Tracking of White Amur at Lake Conway  
—J. Schardt, Florida Department of Natural Resources, Tallahassee, FL  
Recording Fathometer  
—M. Maceina, Univ. of Florida, Gainesville, FL
- 2:15 p.m. Large Scale Operations Management Test of Prevention Methodologies in Washington State (Seattle District)  
—J. Killgore, WES
- 2:30 p.m. Questions
- 3:00 p.m. Final Wrap-up

**THURSDAY, 19 NOVEMBER 1981**  
**TOWN SQUARE BALLROOM—SECTION 2**

- 8:30 a.m.- FY 83 Civil Works R&D Program  
11:00 a.m. Review—R&D Office, OCE (Corps Representatives Only)

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\*Presented as two separate papers herein.

## **ATTENDEES**

### **16th Annual Meeting U.S. Army Corps of Engineers AQUATIC PLANT CONTROL RESEARCH PROGRAM AND OPERATIONS REVIEW**

**St. Paul, Minnesota  
17-19 November 1981**

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## CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U.S. liquid)	3.785412	cubic decimetres
inches	25.4	millimetres
miles per hour (U.S. statute)	1.609347	kilometres per hour
miles (U.S. statute)	1.609347	kilometres
pounds (force) per square inch	6894.757	pascals
pounds (mass) per acre	0.000112	kilograms per square metre
square feet	0.09290304	square metres
square miles	2.589998	square kilometres
tablespoons	147867.6	cubic metres
tons (mass) per acre	0.22	kilograms per square metre
tons (2000 lb, mass)	907.1847	kilograms
yards	0.9144	metres

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\* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula:  
 $C = (5/9)(F - 32)$ . To obtain Kelvin (K) readings, use  $K = (5/9)(F - 32) + 273.15$ .

**16th Annual Meeting  
U.S. Army Corps of Engineers  
AQUATIC PLANT CONTROL RESEARCH PROGRAM**

**INTRODUCTION**

As part of the Corps of Engineers (CE) Aquatic Plant Control Research Program (APCRP) it is required that a meeting be held each year to provide for professional presentation of current research projects and review current operations activities and problems. Subsequent to these presentations, the Civil Works Research and Development Program Review is held. This program review is attended by representatives of the Civil Works and Research Development Directorates of the Office of the Chief of Engineers; the Program Manager, APCRP; and representatives of the operations elements of various Division and District Engineer Offices.

The overall objective of this annual meeting is to thoroughly review Corps aquatic plant control needs and establish priorities for future research, such that identified needs are satisfied in a timely manner.

The technical findings of each research effort conducted under the APCRP are reported to the manager, APCRP, U.S. Army Engineer Waterways Experiment Station (WES), each year in the form of quarterly progress reports and a final technical report. Each technical report is given wide distribution as a means of transferring technology to the technical community. Technology transfer to the field operations elements is effected through the conduct of demonstration projects in various District Office problem areas and through publication of Instruction Reports (IR), Engineering Circulars (EC), and Engineering Manuals (EM). Periodically, results are presented through publication of an APCRP Information Exchange Bulletin which is distributed to both the field units and the general community. Public-oriented brochures, movies, and speaking engagements are used to keep the general public informed.

The printed proceedings of the annual meetings and program reviews are intended to provide Corps management with an annual summary to ensure that the research is being focused on the current operational needs on a nationwide scale.

The contents of this report include the presentations of the 16th Annual Meeting held in St. Paul, Minnesota, 17-19 November 1981.

## COMMENTS ON THE RESEARCH PROGRAM PAST AND FUTURE

by  
J. Lewis Decell\*

During the period 1977-81, the conduct of the Corps' Aquatic Plant Control Research Program (APCRP) followed the approach outlined in the Five-Year Research and Development Plan. The plan was approved by the Office, Chief of Engineers, and was prepared by the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. The plan reflected input from both the scientific community and the users, as provided through the Corps' Research Needs System. The overall objective of each element of the research program was technology transfer to the user. The individual work units were structured such that the end product was either a guidance document outlining how to effectively apply the technology, or provided needed input to such a document. Although fiscal resources consistently fell short of the level identified for an accelerated level of research, many significant accomplishments were made during the last five years. The scientists and researchers of the APCRP have individually distinguished themselves as the Nation's leading experts in their respective areas of endeavor. Collectively, they have established the Corps of Engineers as the national leader in aquatic plant control research. State programs and some other Federal programs have recognized the structure of the APCRP as one that is not only applicable to their local administrative situation, but one that also can prove technically beneficial. Many of the research approaches initiated by these scientists have since been accepted as protocol. During the early years of this period, researchers found it difficult to accept a product other than a report as the direct result of their research effort. I now find it gratifying to realize that this approach is accepted by those who initially voiced hesitation.

I also see that aquatic plant control as a science has finally begun to gain the momentum necessary to pull itself abreast of other, more established technical areas. Universities now teach courses specific to aquatic plant control and the word *control* is the key. The student has always been taught something about aquatic plants, set in the context of aquatic ecosystems in general. But until recent times, they never had the opportunity to learn that there may be a need to *control* these plants, and that the scientific implications involved are not simply the opposite of the classical teachings. As a group, those involved in aquatic plant control can now easily identify themselves as just that—a group, a segment of the population whose scientific and operational interests are common. All aspects of an organized endeavor are present, and the Corps of Engineers has made significant contributions to every phase and every element, be it political, social, fiscal,

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\* U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

scientific, or bureaucratic. In short, the Corps' Aquatic Plant Control Research Program has played a significant role in the progress made to date, rightfully recognized. Our final objective has been and still is to solve existing aquatic plant problems, and develop the technology needed to manage aquatic plants in our waters. For the first time in several years, the pathways to our overall objectives are more clearly defined, and we have learned what it really takes to complete the cycle from research to problem solving.

Beginning this year, we will operate under a new Five-Year Plan. The elements of this plan are presented in more detail than the previous Five-Year Plan. The previous technology areas have been retained as general technical areas. Under these technical areas the work units of research are better defined, and the timetables for completion are readily identifiable. The overall task of research in the future will remain generally unchanged. However, the specific nature of these efforts will necessarily undergo some change. For instance, the goal of developing biological controls for submergent aquatic plants will necessitate research approaches that are much different from those used to develop the agents we now have for controlling emergent aquatic plants. The overall task of management of this research program will be more difficult in the future. Because of our successes in the past, expectations by the users will be greater—and the fiscal outlook is not one that lends itself to acceleration of efforts. This can create a situation that will demand an even higher level of competence than has been necessary before. I am confident that this can be accomplished. The APCRP is presently on the threshold of additional significant accomplishments. In order to ensure the timely completion of these near-ready results, it may be necessary to delay the start of new research, should funding remain at its present level. These decisions will be made and the support necessary to carry out the APCRP objectives will be provided. I think we can and should look forward to an even more productive time in the future.

# USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

## Lower Mississippi Valley Division

by  
Robert L. Tisdale\*

Under the Construction General Program, R&H Act of 1965, the combined efforts of the New Orleans District crews and crews of the State of Louisiana Department of Wild Life and Fisheries were continued against aquatic vegetation problems throughout Louisiana. Waterhyacinth persists as the most serious aquatic pest. Control maintenance by the Corps of cleared areas continued in the Mermentau River, Bayou Lacassine, Bayou Queue de Tortue, in the Bayou Teche Basin south of U.S. Highway 190, including the lakes west of the Atchafalaya Floodway, and in the feeder areas of the Gulf Intracoastal Waterway. Louisiana Department of Wild Life and Fisheries crews continued maintenance efforts in the major lakes and streams of north Louisiana, in the Atchafalaya Floodway, in the Louisiana portion of Toledo Bend Reservoir, and in the Pearl River Basin in Louisiana.

During the fiscal year, 20,757 acres of waterhyacinths was treated in the State of Louisiana. Corps of Engineer crews treated 5,099 acres primarily by herbicides and the State of Louisiana Department of Wild Life and Fisheries crews treated 15,658 acres.

The alligatorweed flea beetle (*Agasicles hygrophila*) and the stem boring moth (*Vogtia malloi*) are exercising significant control of alligatorweed in all locations.

The waterhyacinth weevils (*Neochetina eichhorniae* and *N. bruchi*) have spread throughout all areas of the state infested by waterhyacinth, and adult feed scars are more prevalent on all infestations.

Submerged weed problems in Toledo Bend Reservoir have reached serious proportions and Caddo Lake is experiencing interference with boating and fishing. *Hydrilla verticillata*, an introduced exotic submerged weed species, continues to spread along the Gulf Intracoastal Waterway and poses a serious threat to water-related activities.

Under the Operation and Maintenance General Program, R&H Act of 1899, chemical and mechanical maintenance methods were used to prevent waterhyacinth obstructions and damage to navigation in main waterways and principal tributaries. In some cases where alligatorweed has previously kept waterhyacinth fringes confined along the banks, attack of the alligatorweed flea beetles has reduced its competitiveness and waterhyacinths are multiplying and spreading in the waterways.

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\* U.S. Army Engineer Division, Lower Mississippi Valley, Vicksburg, Mississippi.

Corps personnel treated a total of 10,357 acres of waterhyacinth by chemical and mechanical methods in Black Bayou, Lake Cataouatche and feeder streams, Lake des Allemands area, and the Gulf Intracoastal Waterway. Lower water levels in the Mississippi River and along the coastal area have allowed some additional areas to be placed in a maintenance status.

The outlook for the future is reduced funding for both control operations and research and development. The New Orleans District Aquatic Plant Program hired labor crew will be reviewed in FY 82 in accordance with OMB Circular A-76.

# **USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES**

## **North Pacific Division, Seattle District**

by  
Robert M. Rawson\*

For those of you who are not familiar with the Pacific Northwest, the North Pacific Division is made up of western Montana, most of Oregon and Idaho, and the entire states of Washington and Alaska. The Division is broken up into four Districts — Alaska, Seattle, Portland, and Walla Walla.

The major area of aquatic plant problems in the Division is within the State of Washington where Eurasian watermilfoil has infested several major water bodies. Serious problems are being experienced in several Seattle area lakes, the Pend Oreille River, and the Columbia Basin (which is administered by the Bureau of Reclamation). In addition, milfoil is spreading down the Okanogan system and has established pioneer colonies in the Columbia River.

Eurasian watermilfoil was first identified in Washington in the early 1970's. It began causing localized problems soon after that in Lakes Washington and Sammamish. At the same time, British Columbia began experiencing problems in the Okanogan Lake chain. The problems in the Seattle area and in other parts of the United States and Canada and the spread of milfoil down the Okanogan River from British Columbia convinced the Washington State Department of Ecology that this species posed a serious threat to the waters of the state. In 1977, the Seattle District was asked to establish a statewide program for the prevention and control of Eurasian watermilfoil. At the same time, a cooperative program was initiated with Okanogan County to try to prevent the spread of milfoil from Osoyoos Lake into the Okanogan River until the statewide program could get underway. The State of Washington had the unique opportunity of establishing a program for the protection of water bodies before they were infested. The primary objective of this prevention program was the protection of the Columbia River.

In 1978, the Seattle District was in the planning process and milfoil extended its range in Osoyoos Lake and also entered the Okanogan River.

To assist in establishing an efficient and effective program, the U.S. Army Engineer Waterways Experiment Station in 1979 began a 3-year research effort into prevention techniques. The experimental work done in Washington in many different areas of treatment will be discussed later on in this conference.

During 1979, the Seattle District was still in the planning stages and milfoil was discovered in the Pend Oreille River.

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\* U.S. Army Engineer Division, North Pacific; Seattle District, Seattle, Washington.

In 1980, our planning study was completed and approved by the Office, Chief of Engineers. We signed a cooperative agreement with the Washington Department of Ecology in July establishing a 70-30 cost-sharing program. The work being done by the state in the Okanogan River (operation of a fragment barrier) and Osoyoos Lake (spot treatment of pioneer colonies with 2,4-D) was incorporated into the program. In addition, control work in the Seattle area, Lakes Washington, Sammamish, and Union (mechanical harvesting and fiberglass bottom screens), was initiated under the program.

The discouraging news in 1980 was that milfoil was found by the WES field team at the mouth of the Okanogan River.

Our work in 1981 included continuation of the control work in the Seattle area lakes and the prevention work in the Okanogan River and Osoyoos Lake. In addition, the pioneer colonies at the mouth of the Okanogan River were treated with granular 2,4-D. Unfortunately, during the treatment of these colonies, additional colonies were discovered downstream. We now have milfoil confirmed downstream of Wells Dam.

It appears that milfoil fragments are going downstream, rooting among the native plants, and growing undetected. By the time they become visible from the surface, they are well established and have probably already released fragments downstream. What is needed to run a prevention program in this type of system is some means of early detection and an immediate response capability for the treatment of new colonies. However, with the cost-sharing requirements, permits, environmental analysis, fisheries restrictions, notification of public water users, and Government-contracting procedures, there has been a significant lag time between the detection and treatment of colonies. With this history, it is obvious that a much more aggressive program in the Columbia and Okanogan Rivers is necessary to stop the spread of milfoil downstream. But, this realization comes at a time when we have been notified of a very significant cut in our operating budget. The Corps' cost-sharing program may become a much smaller part of the statewide operation with the State, local governments, and public utility districts having to pick up a much greater share.

Because of the continued downstream spread of milfoil and its appearance in some Oregon lakes, the Portland District was requested by the State of Oregon to study the problem. They are in the process of finalizing their Recon Study this year and have identified milfoil in several scattered locations in western Oregon. They have not yet made an official recommendation, but funding does not appear to be available for a new start this fiscal year.

# **USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES**

## **Aquatic Plant Control Operations Support Center, Jacksonville District**

by  
Joseph C. Joyce\*

The formal establishment of the Aquatic Plant Control Operations Support Center (APCOSC) was announced at the 1980 Program Review meeting in Savannah, Georgia, by Mr. Dwight Quarles (DAEN-CWO-R). The APCOSC is located within the Natural Resources Management Section, Construction-Operations Division, Jacksonville District.

### **CENTER RESPONSIBILITIES**

The policies, functions, and procedures for the utilization of the Center are outlined in Engineering Circular 1130-2-188. The Engineering Circular sets forth the general relationship between the APCOSC; the Office, Chief of Engineers (OCE); and the U.S. Army Engineer Waterways Experiment Station (WES) and establishes the following functions of the Center:

- a. Provide technical guidance to other Corps Districts in the planning phases of aquatic plant control programs, i.e., during the development of survey reports, general design memoranda, Environmental Impact Statements, and consultations required by Section 7 of the Endangered Species Act.
- b. Provide technical guidance to other Corps Districts in the operational phases of aquatic plant control programs, i.e., during development of the technical portions of control contracts with local sponsors or private contractors, or the design and operation of a hired labor program.
- c. Provide technical expertise and/or operational personnel and/or equipment to respond to localized, short-term critical situations created by excessive growths of aquatic plants. Critical situations are considered to be those situations in which severe commercial navigation blockages are occurring, the potential for interference with flood control capability is evident, or when public health is threatened. This type of support will be undertaken only when it is not possible to obtain contractual aquatic plant control (APC) services or when the in-house capability to respond is inadequate.
- d. Provide assistance to OCE for the training and certification of Corps application personnel.
- e. Upon request, assist WES in the field application and evaluation of newly developed control techniques or procedures.

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\* U.S. Army Engineer Division, South Atlantic; Jacksonville District, Jacksonville, Florida.

- f. Provide assistance to OCE in the development of a comprehensive Corps-wide APC program.

### ACTIVITIES TO DATE

Table 1 provides a breakdown of the types of services provided and the types of users to which these services were provided. A total of 81 requests for assistance were received and answered. Sixty-four of these requests were received during FY 81. Thirty-two, or 40 percent of the total requests, were received from other Corps Districts or Divisions. The next most frequent users were State and Federal agencies at 22 and 15 percent, respectively. The most frequently requested activity was APC/Program planning assistance. Twenty-one inquiries (26 percent) either requested information concerning the Corps' APC program or were actual requests for guidance in preparing the necessary documentation for program initiation. The next most requested activity was biological control assistance which involved the shipment of *Agasicles hygrophila* and *Amynothrips andersoni* to several states for control of alligatorweed. The other major activity of the APCOSC was herbicide recommendations for the control of various aquatic plant species. Other than Corps Districts, the Department of Interior was the most frequent requestor.

Two of the more unique requests for support were: (1) an onsite inspection of lakes in the State of Delaware with WES personnel in order to investigate a filamentous algae (*Lyngba* sp.) problem (APCOSC personnel also discovered the presence of hydrilla in three lakes in Delaware. This plant had previously been identified as *Egeria* and has subsequently been found in other Delaware lakes), and (2) Australia requested computer program documentation on field operations monitoring system.

Table 1  
Aquatic Plant Control Operational Support Center  
Requests for Support Through 30 Sep 81

<i>Activities</i>	<i>Foreign Countries</i>	<i>Federal Agencies</i>	<i>WES</i>	<i>COE Districts</i>	<i>State Agencies</i>	<i>Industry</i>	<i>Individuals</i>
Herbicide recommendations	1	5	-	5	3	-	-
Onsite visits	-	1	-	1	1	-	-
Biological control assistance	-	3	3	4	6	-	-
APC program planning assistance	-	1	-	10	6	3	1
Contract specification assistance	-	-	-	6	1	-	-
Training assistance	-	-	-	3	-	-	1
Miscellaneous	2	2	3	3	1	5	-
Total	3	12	6	32	18	8	2
Grand total 81							

## **STATUS OF APCOSC PROGRESS**

It is obvious from the number and types of requests received by the APCOSC that the purpose for which the Center was established is being met. There are, however, numerous programs in which the Center should be more involved which have not been initiated due to the lack of adequate manpower. Examples of such activities include: (1) development of operational manuals for chemical, biological, mechanical, and integrated control programs; (2) in conjunction with OCE, development of guidelines for APC program initiation; (3) public information pamphlets concerning the Corps' APC program; (4) survey of other Corps Districts in order to determine scope and magnitude of the operational APC problem; and (5) development of training materials for APC applicators and/or contract inspection personnel. Item 1 above would require coordination with WES to ensure that there is minimal overlap with the WES Technology Transfer Work Unit which coordinates the timely transfer of research results. Based on the number and type of requests received by the APCOSC, the proper completion of the above functions would greatly assist the Corps and others involved in aquatic plant management in the development of viable, responsive APC programs.

## **PROBLEMS AND CORRECTIVE ACTIONS TAKEN OR PROPOSED**

The major problems affecting the APCOSC and the overall APC program in general are staffing and funding. During contacts with State agencies and other Corps Districts, the APCOSC has made every attempt possible to encourage participation in the APC program when eligible and justifiable. As more states and Districts become involved in the program, the current distribution of the APC program funds will require review. Such a review should not only encompass the distribution of the operational funds, but also the R&D funds unless Congress can be encouraged to raise the \$5.0 million funding cap. Even in this period of austere budgeting philosophy, the rapidly spreading aquatic weed problems and the interest other states are showing in the program should provide a wider basis of Congressional support for the program and funding above the \$5.0 million limitation.

## **USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES**

### **South Atlantic Division, Jacksonville District**

by  
James T. McGehee\*

Fiscal year 1981 was somewhat unusual for the Jacksonville District's operational program. It was a very dry year, which influenced the growth and control of aquatic plants. Many waterhyacinth plants that normally require treatment were stranded on the bank by receding water and were either killed by drying or were unreachable for treatment by conventional methods. The plants that survived grew and reproduced at a much reduced rate and, therefore, do not pose an immediate threat. Hydrilla was also stranded on shorelines exposed during this natural drawdown of the state's water bodies. Some of the lakes normally treated under the control program were not accessible to the using public or contract treatment crews because of the excessively low water. The new effect of the low water conditions was a reduction in the control operations required for FY 1981.

The year also brought the first extensive Section 7 consultation with the U.S. Fish and Wildlife Service under the Endangered Species Act. A herbicide residual monitoring study was undertaken in Kings Bay, Crystal River, Florida, to *determine the probability of copper toxicity effects on the endangered Florida manatee as a result of copper applications for hydrilla control.* Preliminary results of the monitoring indicated that copper levels in water and plants returned to preapplication levels within a few days of treatment. These data together with existing literature will be compiled into a Biological Assessment for presentation to the Fish and Wildlife Service early in calendar year 1982. A favorable finding in the assessment and concurrence by the Fish and Wildlife Service will allow the continued use of copper compounds for hydrilla control in this critical habitat area of the manatee.

Another regulatory matter severely limited the District's ability to control hydrilla statewide. The Florida Department of Agriculture and Consumer Services issued a stop sale order on the special Local Needs (Section 24c, FIFRA) labels of three herbicide products. This eliminated all effective registered products for the control of hydrilla in flowing water sites. One product remained for this use but it has not been proven effective by itself. The action was precipitated by the Environmental Protection Agency's (EPA) notification of lack of approved tolerances for these products. The District has forwarded a request through OCE to

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\* U.S. Army Engineer Division, South Atlantic; Jacksonville District, Jacksonville, Florida.

EPA for a specific exemption from registration under Section 18 of FIFRA. Approval of the exemption request will allow hydrilla control operations to continue at the present level for one year.

### WATERHYACINTH

Maintenance control of waterhyacinth was continued in Florida during FY 1981. No significant problems were caused by the plants over the entire year, partially due to the low water conditions but primarily due to the low residual levels of plants attained through the maintenance control approach. The use of EPA-registered herbicides (2,4-D and Diquat) has been the primary method of control. Three insects have been released and distributed over most of the state: *Neochetina eichhornii*, *N. bruchi*, and *Sameodes albigutalis*. The insects are obviously feeding on the plants and are probably reducing the rate of reproduction of the plants.

However, this reduction has not been sufficient to keep the plants within acceptable limits in most areas; thus, herbicide control has remained the primary control method. Mechanical control has only been used in very small-scale applications to remove sporadic jams of plants at bridges. Where waterhyacinths and water lettuce are found growing intermixed they have been treated together by the use of Diquat. This effectively controls both species. The total area of waterhyacinth treated during FY 1981 was 19,560 acres,\* and the area of waterhyacinth/water lettuce mixed was 8,620 acres.

### HYDRILLA

Control operations on hydrilla were also primarily performed by herbicide application. Diquat and copper in combination or endothall compounds were the main herbicides used. This was the beginning of the third year of operational control of hydrilla utilizing water level fluctuation in Lake Ocklawaha, Cross Florida Barge Canal Project. Operational monitoring indicates that hydrilla control in the fluctuation zone is being attained. However, results of the fluctuating water levels on hydrilla in deeper water are not certain. The Limnos harvesting system owned by the District was used in Orange Lake near Gainesville, Florida, again this year. Approximately 150 acres were cut and maintained during the growing season in this lake at a cost of \$100,000. Total acreage of hydrilla treated statewide was 12,570.

### MINOR PLANTS

The District's Minor Plant Program is directed to those plant species, introduced and native, that profusely grow and restrict navigation usage. These plants are not of widespread concern but, on a local scale, are as use restrictive as the

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\* A table of factors for converting U.S. customary units of measurement to metric (SI) is presented on page xii.

waterhyacinths or hydrilla. They often may replace these two species following control operations directed specifically at waterhyacinths or hydrilla. Control operations consisted of the use of several different EPA-registered herbicides selected for their activity against the target species. Total acreage of minor plants treated during the fiscal year was approximately 2,340 acres, or 5 percent of the total acreage of nuisance species treated during the year.

## **PUERTO RICO**

Puerto Rico and the U.S. Virgin Islands are within the Jacksonville District's boundaries. The District has been working with the Government of Puerto Rico for several years to start an APC program for waterhyacinth control in the island's lakes and rivers. The final Environmental Impact Statement (EIS) and the General Design Memorandum (GDM) have been forwarded to OCE for final approval and filing. The Department of Natural Resources (DNR) is the local sponsoring agency. The Cooperative Agreement has been executed and operations will begin in fiscal year 1982 following filing of the EIS and GDM and approval of DNR's annual work and safety plans. Puerto Rico's environmental agency, the Environmental Quality Board, has expressed concerns about the possible effects of 2,4-D on the flora and fauna of Puerto Rico that is different from that in the United States. For this reason, the initial planned efforts will be relatively small scale and monitoring will be performed to determine 2,4-D residues in the Puerto Rico environment.

## **JACKSONVILLE DISTRICT OUTLOOK**

Funding and personnel reductions in FY 82 will affect the amount of control work performed and the agencies performing the work. It appears that the District's program will take a 42 percent budget cut in APC and over 50 percent reductions in personnel from FY 81 levels. The operations performed by Corps personnel to be cut will be directed to the State of Florida for performance by their subcontractors. The lasting effects of the low water conditions and the expected continuance of low water during the normal winter dry season will help to reduce the impact of the budget reduction. However, similar funding in FY 83 under normal water level conditions could be disastrous.

The Section 7 consultation and the Section 18 exemption are expected to be completed and approved in time for the usual spring treatments of hydrilla.

# **USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES**

## **Southwestern Division, Galveston District**

by  
C. R. Harbaugh\*

The Galveston District's aquatic plant management program consists of a cooperative cost-sharing and contractual agreement between the Federal Government and the Texas Parks and Wildlife Department. Field operations are carried out by the Texas Parks and Wildlife Department.

Primary activities currently consist of control of waterhyacinth and alligatorweed in southern and southeastern Texas. Most of this work is performed within 100 miles of the Texas coast.

Estimates of existing acreages of waterhyacinth and alligatorweed were made during May 1981. A total of 16,000 acres of waterhyacinth were estimated for ten Texas work areas compared with 6,980 acres reported in May 1980. Total infestations of alligatorweed were estimated to be 18,000 compared to 11,410 acres reported in 1980.

The waterhyacinth problem is presently most severe in the North Coastal area and the Sabine River Basin. The Trinity, Neches, Nueces, San Jacinto, and Guadalupe River Basins are also problem areas that require frequent herbicidal treatment. Currently, alligatorweed most critically infests the Trinity and Sabine River Basins and the North Coastal area; however, extensive infestations also occur in the Neches and San Jacinto River Basins.

Hydrilla infestations continue to be a serious problem in portions of Texas. Approximately 10,000 acres of hydrilla was reported in Texas in 1981, compared with 8,000 acres in 1979 and 2,900 acres in 1977. The most serious problem presently occurs in Lake Conroe in the San Jacinto River Basin where about 29 percent (6,000 acres) of the 21,000-acre lake is infested.

The control of hydrilla is not currently authorized as part of the Galveston District's program. However, economic and environmental studies are scheduled for completion during FY 82. These studies are being made in order to supplement the General Design Memorandum (GDM) and Environmental Impact Statement (EIS) to include control of the species in Texas. Treatment to date has primarily involved experimental control on Lake Conroe and Lake Livingston by the Texas Parks and Wildlife Department and studies by Texas A&M University funded by the State of Texas.

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\* U.S. Army Engineer Division, Southwestern; Galveston District, Galveston, Texas.

During our studies to revise the GDM and EIS, we found two problems that needed to be resolved before we could develop a comprehensive management plan for aquatic plant control. First, we needed a cost-effective and rapid method of problem identification and assessment of aquatic areas within the state. Second, we found that biocontrol technology available for control of alligatorweed and waterhyacinth had been marginally effective or had not been implemented in the state.

After preliminary discussions of these problems with personnel of the U.S. Army Engineer Waterways Experiment Station (WES), the WES submitted a proposal to the Galveston District that provided a series of tasks which, when completed, would provide the Galveston District with an aquatic plant survey and the introduction and evaluation of all species of insects and plant pathogens available for the biocontrol of alligatorweed and waterhyacinth in Texas. In addition, the status of previously introduced insect species on alligatorweed was to be investigated, with special emphasis placed on the determination of environmental factors that may be limiting the effectiveness of these insects in controlling alligatorweed. Galveston District funded the proposal in May 1980 and research efforts were initiated in June 1980.

The specific objectives of the 3-year program are:

- a. Determine which remote sensing and ground reconnaissance methodologies can be implemented by the Galveston District for surveying different plant types in different settings.
- b. Assist in updating the Galveston District's aquatic plant control GDM.
- c. Determine the organisms currently impacting alligatorweed and waterhyacinth in Texas.
- d. Establish the full complement of available biocontrol agents on waterhyacinth and alligatorweed in Texas.
- e. Identify factors that may be limiting the effectiveness of biocontrol agents.
- f. Develop strategies for management of the biocontrol agents that will provide more effective control of alligatorweed and waterhyacinth.

When completed, this program is expected to result in improved techniques for District-wide aquatic plant surveys and will greatly increase the capability of the District in development of better aquatic plant control methods.

## USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

### South Atlantic Division, Charleston District

by  
James W. Preacher\*

The Charleston District began its Cooperative Aquatic Plant Control Program in 1960. At that time, the District contracted with the South Carolina Public Service Authority to control alligatorweed in the Santee-Cooper Lakes. The Santee-Cooper Lake system is composed of two major bodies of water, Lake Marion (155 square miles) and Lake Moultrie (95 square miles). The State furnished the manpower and equipment, and the Federal Government furnished the herbicide, granular silvex, 2,4-D, and funds of up to 70 percent of the cost of field operations.

Seven years later, 1967, the contract was terminated because of the reduction of alligatorweed, limited funds, and because there was greater need for aquatic plant control in other waters of the State. That same year a new contract was signed with the South Carolina Department of Agriculture to control aquatic plants in all State waters except the Santee-Cooper Lakes. Alligatorweed was again the only target species. Infestations of the plant were so severe that portions of some streams were impassable. A total of 166 miles of streams and rivers was treated with a 40 percent amine formulation of 2,4-D. This treatment program was terminated in 1975 because no 2,4-D formulations were then labeled for use on alligatorweed in flowing waters in South Carolina. More importantly, however, a steady decline of alligatorweed was noted with the introduction and successful establishment of the alligatorweed flea beetle and stem borer through the cooperative efforts of the Corps and the U.S. Department of Agriculture.

From this brief background one might conclude that South Carolina is currently living contentedly with an effective biological control program, essentially free of noxious aquatic plants. Unfortunately, that is not the case. Two additional exotic aquatic plants, Brazilian elodea (*Egeria densa*) and water primrose (*Ludwigia uruguayensis*), have rapidly infested State waters. Brazilian elodea by far the more troublesome of the two noxious species, is a submersed aquatic that is rooted in the substrate. Water primrose is an emergent plant which can readily spread over the water surface using elodea for support.

Today, approximately 30,000 acres of South Carolina waters is infested with Brazilian elodea. The bulk of elodea (approximately 80 percent) occurs in Lake Marion. Water primrose is a nuisance in approximately 9000 acres of State waters. Again, the majority (66 percent) occurs in Lake Marion.

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\* U.S. Army Engineer Division, South Atlantic; Charleston District, Charleston, South Carolina.

What is the Charleston District doing to correct the problem? A new General Design Memorandum and Environmental Impact Statement were prepared in 1980 to initiate another Cooperative Aquatic Plant Control program. Under the new program, the South Carolina Water Resources Commission heads a council of State agencies which administers aquatic plant control activities in all State waters including the Santee-Cooper Lakes. The new control program includes three target species: Brazilian elodea, water primrose, and alligatorweed.

As is often the case, the first problem encountered was the lack of direct funding for the program during FY 81. However, the District obtained \$56,000 of surplus funds from the Jacksonville District. As soon as the money became available, we negotiated a contract and initiated a spraying program in upper Lake Marion. Before the end of FY 81, we had used all available funds and, in the process, successfully treated 500 acres of elodea- and primrose-infested waters. The State provided the labor, equipment, and chemicals, and the Federal Government provided funds of up to 70 percent of the costs of field operations. Excellent control of both species was obtained using 2 gal of diquat and 1 gal of invert solution per surface acre of treatment area.

In conclusion, the Charleston District has a very serious noxious aquatic plant problem that is continuing to worsen. Currently, the main problem is one of limited funds. The District does not anticipate receiving any funds for aquatic weed control operations during FY 82.

# **USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES**

## **South Atlantic Division, Mobile District**

by  
Mike Eubanks\*

Aquatic plant control activities in the Mobile District fall under three broad organizational categories: the Aquatic Plant Control Program (APCP); the 1899 Removal of Aquatic Growth (RAG) Program; and the aquatic plant control activities on Corps projects (i.e., Lake Seminole).

The largest advance in the Mobile District program during 1981 was the initiation of the Alabama APCP. Most activities involved completing the necessary paperwork in order to comply with appropriate regulatory "hurdles." This paperwork included the State design memorandum, NEPA documents (environmental assessment), and cost-sharing contract with the Alabama Department of Conservation and Natural Resources (ADOCNR). These were completed in September 1981; therefore, no field operations under the statewide APCP were accomplished in FY 1981.

The Mobile District and the ADOCNR, however, did carry out many informal aquatic plant control tasks. These tasks revolved primarily around the Eurasian watermilfoil infestations of the Mobile Delta and hydrilla infestation of Coffeerville Reservoir (Corps reservoir on the lower Tombigbee River). Work in the Mobile Delta included monitoring of the aquatic plant growth, a public awareness campaign concerning introduction of exotic species into local waters, field investigation of reported hydrilla infestations, reintroduction of *Agasicles* on alligatorweed, interfacing with Alabama Coastal Area Board (CAB) contractor surveying submersed aquatics, and acquisition of fall 1980 color infrared (IR) photography of the Delta. A good working relationship has been established with the ADOCNR and they are enthusiastic about initiating the fieldwork. The CAB survey shows, according to preliminary estimates, that milfoil appears to be at about the same level as observed in the ADOCNR 1979 survey, which revealed an infestation of approximately 3600 acres. Hydrilla has not yet been found in the Delta or in the Tombigbee River below Coffeerville Lake. A large increase in southern naiad (*Najas quadalupensis*) was noted early in the growing season but milfoil had overtopped and out-competed it by September. Public awareness was increased through the use of several newspaper articles, local TV news spots, and meetings with local sportsmen and conservation groups.

At the request of the State, the Mobile District participated in a work agreement to combat the hydrilla problem (about 15 acres) in Coffeerville Reservoir. This

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\* U.S. Army Engineer Division, South Atlantic; Mobile District, Mobile, Alabama.

involved three herbicidal treatments by the ADOCNR during 1981. The first two were with Aquathol K and Nalquatic and the last with Hydout. Approximately a 50 percent reduction was observed. The remaining growth was in an area of rapid water exchange, thus exhibiting the poor percent kill. Although only 15 acres of hydrilla was observed in October, the treatments were thought to be justified in order to restrict its spread in the State of Alabama to the maximum extent possible.

In the past years, the RAG Program in the Mobile District involved Mobile Area Office spray crews treating waterhyacinths in the Mobile Delta. This program was discontinued based on local objections, current lack of a significant program, and funding limitations.

Thanks to the Jacksonville District, several reintroductions of the alligatorweed flea beetle were made in June 1981. These were in the city of Mobile and in the Mobile Delta.

The other major area of aquatic plant control activities in the Mobile District is Lake Seminole. The primary efforts there during 1971 were WES R&D activities, which will be covered by other presentations at this meeting. However, some promising test results have been observed on an aerial application of Roundup on about 15 acres of giant cutgrass (done under an Experimental Use Permit by Lake Seminole personnel).

Two interesting notes downstream of Lake Seminole include the first reported hydrilla infestation on the Apalachicola River and the first survey of Eurasian watermilfoil in the Apalachicola Bay system. Lake Seminole personnel report that a small patch of hydrilla is growing in the barge canal at the Jackson County, Florida, Port Authority. The Florida DNR reports that approximately 500 acres of milfoil is growing in Round Bay, a part of the Apalachicola Bay system. Under the current division of responsibility, the Jacksonville District is responsible for the APCP in this area.

Some interesting aquatic plant growth patterns have been observed in the Mobile Delta since Hurricane Frederic devastated the area in September 1979. *Egeria densa*, which was fairly common in the Delta and had been reported to infest up to 500 acres, has not been collected there since the hurricane. Waterhyacinth also decreased and has only been observed in a few scattered patches during 1981.

Another point of interest involves the growing conflict between the wetlands preservation interests and aquatic weed control interests. These conflicts (often within the Corps) have often been observed to deal from emotion more so than scientific knowledge. This is somewhat understandable since building a case based on scientific knowledge on the habitat values of an aquatic plant colony is equaled by the task of quantifying the benefits and costs of an aquatic plant control operation. Many unquantifiable parameters are experienced on both sides of the issue. We at the Mobile District are continuing to strive to balance the environmental and economic factors on a case-by-case basis.

# **USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES**

## **Control of Aquatic Plants in Lake Champlain, Vermont**

by  
Simeon Hook\* and Richard Maraldo\*

After a number of years of no active aquatic plant control program, the New York District is presently involved in a project to control the spread of waterchestnut into northern Lake Champlain, and Eurasian watermilfoil in St. Albans Bay and Mallett's Bay, Vermont. There are approximately 300 acres of waterchestnut and 20 acres of yellow floating heart in Southern Lake Champlain and 690 acres of Eurasian watermilfoil in St. Albans Bay. Both the southern lake and St. Albans Bay provide a source of drinking water to the area and are heavily used for various water-related activities. The Vermont Department of Water Resources and Environmental Engineering, in 1979, requested assistance from the Corps in developing and funding a nuisance control program for Lake Champlain. A reconnaissance report, a General Design Memorandum, and an Environmental Assessment were completed and the work is scheduled to begin in the summer of 1982, with the State of Vermont acting as the local cooperating agency.

### **RECOMMENDED CONTROLS**

The two elements of the program studied in detail were the control techniques and the disposal alternatives. The recommended control technique is mechanical harvesting and hand-pulling for the Southern Lake and mechanical harvesting for St. Albans Bay. All harvested plants will be transported to upland disposal sites. The 10-year cost for this program is \$1,080,000 with a benefit-cost ratio of 32.5 for the Southern Lake and 2.5 for St. Albans Bay.

### **CONTROL ALTERNATIVES**

Various alternatives were considered for the management and control of nuisance aquatic macrophytes. Habitat manipulation; biological, chemical, and mechanical control methods; and the no-action alternative were investigated for potential inclusion in the Lake Champlain aquatic plant control program. The recommended plan utilizes harvesting machines. These harvesting machines range from boats mounted with sickle-bar mowers to elaborate, specially designed devices that simultaneously cut and remove the plants from the water.

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\* U.S. Army Engineer District, New York; New York, New York.

## DISPOSAL ALTERNATIVES

Disposal of massive quantities of harvested vegetation is the major logistical problem associated with mechanical harvesting. The conventional disposal procedure involves removing the vegetation from the water and, in large-scale operations, trucking it away from the shoreline to disposal sites. This is the disposal technique proposed to accompany the harvesting operation in St. Albans Bay.

Disposal of harvested vegetation in southern Lake Champlain poses a unique problem because of the limited accessibility of the area to vehicular traffic. Application of the conventional disposal technique to a full-scale waterchestnut eradication and control program would be infeasible as a result of the local topography; therefore, alternative plant disposal methods were explored in depth. These alternatives include: (1) onshore dumping above the water line, (2) use of cribs located in shallow water or near shore to physically contain the harvested plants, (3) use of a hyballer plant chopping system, and (4) disposition of the vegetation into a barge for temporary storage prior to transport to unloading sites.

The recommended procedure for the disposal of harvested vegetation is transport to shore by the laden harvester, unloading of the vegetation via a shore conveyor into an awaiting dumptruck, and removal from the area to a suitable disposal site.

## CONTROL IMPACTS

The positive and negative impacts of each nuisance control alternative were examined to assess their ecological consequences. The no-action alternative would produce a negative environmental effect as the aquatic nuisance problem would continue to spread. Biological control methods could cause detrimental consequences, as the technology for their use is not highly developed at this time. These controls, however, do offer promise for low-impacting use in the near future. Habitat manipulatory techniques, which involve drastic and large-scale control measures, can produce very detrimental effects. Chemical controls pose a threat to environmental and public health concerns. Mechanical control methods have been shown to have little significant impact on components of the environment outside of rooted macrophytes. Mechanical harvesting is proposed for implementation in the Lake Champlain aquatic plant control program.

Implementation of the no-action plan would allow the existing aquatic nuisance problem to expand, causing even more serious environmental impacts than experienced to date. The aesthetics, or scenic qualities, of this prime tourist region are degraded by increasing macrophyte growth. Wildlife and fish habitat are reduced when species invade open waters and take over shoal areas used for spawning. Fish populations become stunted and overpopulated because dense weed growth favors the survival of forage fish which are normally consumed by

predator species. High dissolved oxygen levels, critical for fish survival, would be lowered by decaying vegetation and its respirational oxygen demands. The diversity of submergent and emergent plant species would be reduced by competition from nuisance species leading to the possible development of monotypic plant communities. Navigation, especially of pleasure craft, would be impeded by dense macrophyte growth.

Waterchestnut, if left unchecked, will eventually spread to all regions of Lake Champlain. Hence, the magnitude of the above-mentioned impacts would be enormous. At the present time, an economic and logistically feasible control could be undertaken; however, the spread of the waterchestnut will negatively affect the benefit-cost ratio and the feasibility of a control program if implementation is delayed.

Mechanical harvesting has been shown to have no significant impact on the aquatic environment. Short-term physical and chemical changes in the water column brought on by harvesting may include a temporary increase in turbidity resulting from perturbation of the sediments, potential leaching of nutrients from severed stems, increased light penetration, and decreased evapotranspiration. Phytoplankton blooms or increases in filamentous algae may result from the pumping of nutrients from damaged macrophyte stems or from nutrients made available from suspended sediment material. A lake restoration project conducted by the Vermont Department of Water Resources and Environmental Engineering to evaluate the lake restorative capabilities of mechanical harvesting, however, showed that there was no significant correlation between harvesting operations and total phosphorus and chlorophyll-a concentrations in surrounding waters.

Long-term (weeks to months) physical and chemical changes include potential increased erosion of the littoral zone resulting from macrophyte removal leading to resuspension of sediments, and decreased pH as a consequence of depressed community photosynthesis. Decreased cover for fish results from harvesting, which may improve the fishing. Dense beds of macrophytes may result in stunted and overpopulated fish populations as a result of decreased predation. Mechanical harvesting would alleviate this situation.

This selective macrophyte control afforded by harvesting allows for the avoidance of monotypic stands of desirable species or important beds of vegetation. This selectivity is a major factor that minimizes the environmental impact of mechanical harvesting. Direct loss of fish can result from harvesting, but the loss is negligible (8.9 kg of fish per hectare harvested) and involves mostly juvenile fish, which would probably be culled naturally.

Removal of the harvested vegetation provides for positive impacts. Depletion of dissolved oxygen and nutrient release by the decaying vegetation will not occur. Vegetation fragments, capable of regeneration, are produced by harvesting, but removal of the harvested vegetation limits vegetative regrowth. Aesthetics are also improved by the cutting and removal of nuisance vegetation.

## DISPOSAL IMPACTS

Onshore uncontained disposal is not employed since this would defeat the purpose of the control program because the seeds could easily be washed back into the lake. Large piles of decaying vegetation may also serve as a habitat for insect pests which threaten public health. In addition, potential odor and aesthetic problems would be likely.

The use of shallow water cribs was not considered at this time largely as a result of very little available documentation regarding the impact of cribbing. Some of the areas of potential concern were found to be depletion of dissolved oxygen by the decaying vegetation, the release of nutrients by the harvested vegetation, and the related anticipated increase in phytoplankton biomass. Odor and health problems are also of concern, as are negative navigational, aesthetic, and recreational impacts.

The impact of the use of a hyballer, a type of harvester which chops the vegetation as it is cut and blows it into the air and onto the water surface, is also considered to be negative. The biological oxygen demand that would be exerted by this mass of chopped decaying vegetation on the surrounding water would be great. Public health and recreation would be negatively impacted by the resulting large mats of floating vegetation.

Temporary storage of harvested vegetation on a barge would have little significant impact on the environment. Odors and insect problems might arise if an open flatbed barge is used. Loss of plants with viable seeds is also a potential problem. Measures would also have to be taken to ensure that the barge will not interfere with the movement of commercial barge traffic in southern Lake Champlain. While this alternative has minimal negative impacts, it was determined infeasible for economic and logistical reasons.

# **MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT**

## **An Overview**

by  
H. Wade West\*

## **INTRODUCTION**

Mechanical control research will provide the technology base required to permit the Corps of Engineers (CE) to carry out its responsibilities in the control of aquatic plants by use of mechanical control methods and procedures. Coordination necessary to carry out this research has been maintained on a continuing basis with the various Corps Districts and Divisions so that the mechanical control research can be used operationally in a timely manner.

## **OBJECTIVE AND TECHNICAL AREAS**

The objective of the mechanical control research work is to develop technology and design concepts and techniques to be used to develop improved mechanical equipment and operating procedures for controlling floating, submerged, and emergent aquatic plants in Corps waterways (rivers and lakes). The research presently includes: (1) development of analytical models, (2) experimental testing and evaluation of existing mechanical control equipment, (3) development of procedures and techniques for successful field deployment of mechanical control equipment, (4) evaluation of water quality effects of water disposal of mechanically processed plant material, and (5) development of design specifications for new equipment. The U.S. Army Engineer Waterways Experiment Station (WES) research will provide practical methodology for effective deployment of existing mechanical systems in terms of environmental constraints.

## **DOCUMENTATION OF FY 81 RESEARCH**

The FY 81 mechanical control research is summarized by the following papers:

- a. Field Test of Aquatic Disposal of Chopped Hydrilla.
- b. Simulation Modeling of Mechanical Control Systems.

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\* U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

# MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

## Field Test of Aquatic Disposal of Chopped Hydrilla

by  
Bruce M. Sabol\*

### BACKGROUND

The Limnos mechanical harvesting system, which is used by the Jacksonville District (SAJ) for operational aquatic plant control, is the only system currently available with an onboard mechanical processor. This processor is a hammermill which chops the harvested plants into short fragments, thereby achieving a great reduction in the volume of harvested hydrilla. With the Limnos system, the processed plant material is placed in a separate barge that transports the material to a shore take-out point.

A mechanical harvesting system such as this commonly has a number of operational problems. Frequently, it is difficult to locate a suitable shore take-out point near the harvesting site, and long transport distances cause delays in harvesting if the harvester has to wait on the transport barges. Also, additional personnel and maintenance costs are required to operate the transport units, resulting in added cost for the control operation. Preliminary testing of the Limnos system and predictions obtained using the WES HARVEST computer model\*\* indicate that the onshore take out of harvested and processed aquatic plants is consuming an unreasonable amount of time and cost during the control operation, accounting for 50 percent or more of the operational time and cost.

Since the plants harvested with the Limnos system are finely chopped, it is possible to immediately return them to the water. To examine the environmental effects of this disposal practice, a detailed field study was conducted in Orange Lake, Florida, during the summer of 1981, as part of the Large-Scale Operations Management Test for the Jacksonville District.

The main objective of the study was to determine the environmental and water quality effects of aquatic disposal of chopped hydrilla. Based in part on a pilot study conducted the previous summer,† three specific objectives were addressed:

- a. Effects of disposal on the oxygen regime of the water.

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\* U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

\*\* See paper by Hutto beginning on page 33.

† Sabol, B. 1981. "Aquatic Disposal of Processed Hydrilla," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-20 November 1980, Savannah, Georgia*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

- b. Type and rate of release of nutrients from the disposed material and subsequent algal response.
- c. Potential for repropagation of the processed hydrilla fragments.

## METHODOLOGY

A study area was selected in the southwest portion of Orange Lake, Florida. Three nonadjoining square plots (1.43 acres) were established in an area of uniform depth (7.5 ft) and plant density (20 tons/acre, harvestable density). Plants in the plots consisted of surface matted hydrilla (*Hydrilla verticillata*) interspersed with coontail (*Ceratophyllum demersum*) near the bottom. Hydrilla was rooted at around 5 ft, and a thick layer of light anaerobic hydrosol blanketed the bottom.

One experimental treatment was assigned to each of the three plots. The first plot was used as a reference; i.e. no harvesting was performed. In the second plot, plants in the 0- to 5-ft layer were harvested and removed by barges; this was designated as the harvest plot. In the third plot, plants in the 0- to 5-ft layer were harvested, chopped by the hammermill, and then allowed to immediately fall back into the water; this was designated as the disposal plot. All plots were in close proximity to each other and thus were subject to identical meteorological conditions. Therefore, the effects of external environmental conditions were assumed to be the same for all plots and the treatment effects were discerned by comparing the results obtained from the different plots. The effects of harvesting alone were assessed by comparing the harvest plot with the reference plot. The additional effects attributable solely to aquatic disposal were assessed by comparing the disposal plot with the harvest plot.

Six randomly selected, buoy-marked stations were located within each plot. Measurements of water temperature, dissolved oxygen, and specific conductance were taken at each 0.25-m depth at each station in each plot; sampling was performed at dawn and in the late afternoon. Three water samples for analysis of photosynthetic pigments were collected from the 0.5-m depth in each plot every other day during the period of the test. Field sampling was conducted for 11 days prior to and 24 days after the harvesting operation.

Harvesting and disposal operations were conducted on 20 July 1981. During harvesting, samples of the chopped plant material were collected for various laboratory tests and analysis, and to determine the fragment regrowth potential. Laboratory tests included determination of settling characteristics, specific gravity, bulk chemical composition, time-dependent solute release, oxygen demand, and nodal and length distribution of the hydrilla fragments.

Fragment regrowth potential was determined by placing a given amount of the harvested and chopped plant material into in situ chambers (Figure 1). The chambers were monitored for several weeks until all fragments had either regrown or had decomposed.

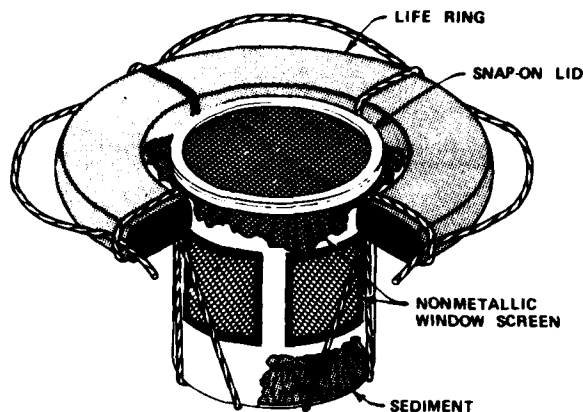


Figure 1. In situ plant fragment regrowth chamber

## PRELIMINARY FINDINGS

A detailed discussion of the methods used, analysis performed and the results are presented in Sabol (1982).<sup>\*</sup> For the purposes of this paper, only the preliminary findings considered significant are described herein.

### Vertical mixing and temperature

All plots showed a diel pattern of unstratified, homothermal conditions in mornings changing to sharp thermal stratification by afternoon (Figure 2). Removal of the hydrilla plants in both the harvest and disposal plots resulted in a decrease in afternoon stratification indicating improved vertical water mixing. Horizontal mixing was also assumed to be improved, although no attempt was made to measure this. Depth-integrated mean temperature and diel temperature fluctuation for morning and for afternoon were not significantly different between plots.

### Oxygen regime

It was hypothesized that disposal of the processed hydrilla material would result in an oxygen sag observable during the diel period of minimal oxygen content that occurs in the morning. No such effect was observed in the disposal plot (Figure 3). Morning minimums were not significantly different between plots before or after harvesting. A short-lived (less than 24 hr) and slight decrease in oxygen did occur in

<sup>\*</sup> Sabol, B. "Environmental Effects of Aquatic Disposal of Processed Aquatic Plants," Technical Report (in preparation), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

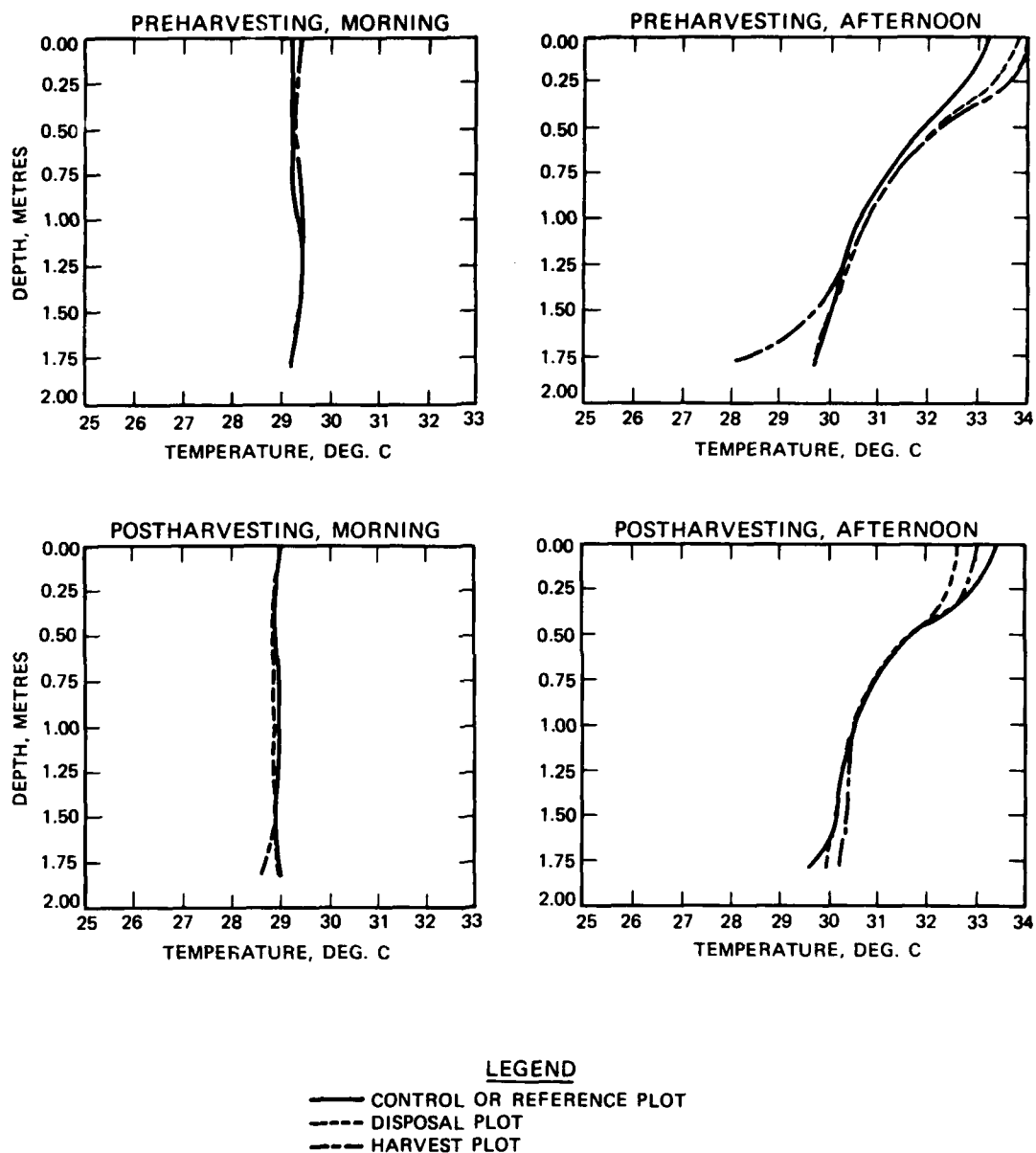


Figure 2. Plot mean vertical temperature profiles by phase and event

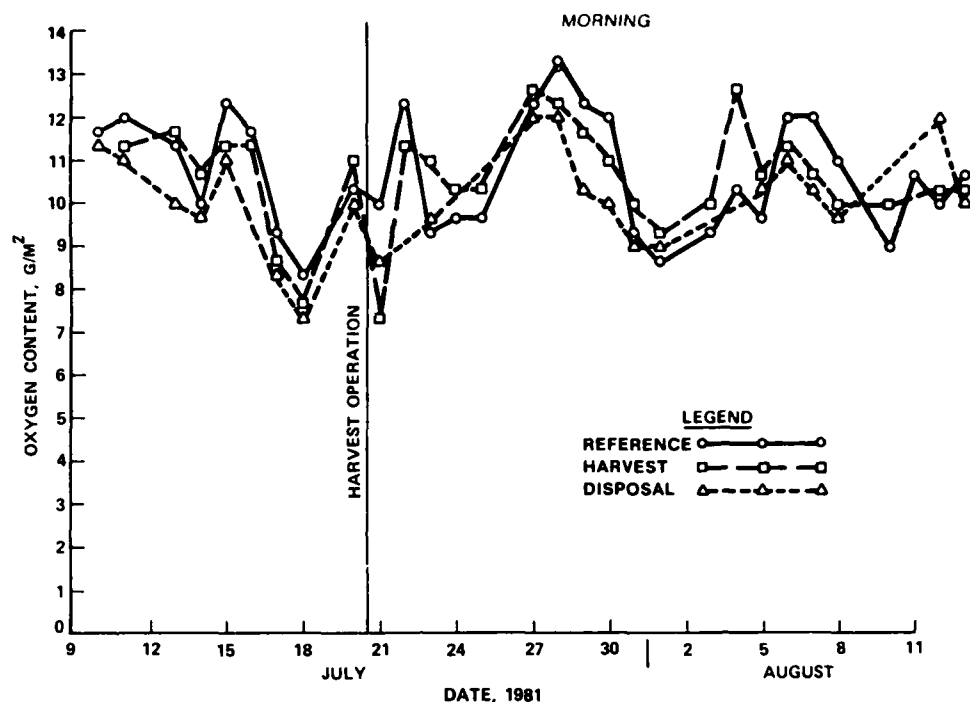


Figure 3. Mean morning dissolved oxygen content in test plots

the harvest and disposal plots immediately after harvesting. This decrease was believed to have been caused by the stirring up of the light anaerobic hydrosol by the harvester's paddle wheels.

Harvesting and disposal resulted in a reduction of the afternoon oxygen maximum (Figure 4). Diel accrual of dissolved oxygen, or afternoon oxygen maximum minus the morning minimum for the respective stations, was equivalent to net primary production uncorrected for atmospheric exchange. Plant removal in the harvest and disposal plots reduced mean diel oxygen accrual by approximately 50 percent (Figure 5). This effect was expected since the aquatic macrophytes and their associated attached algae are the principal photosynthetic organisms in the water column.

The lack of a detectable oxygen sag as a result of disposal of the chopped plant material is surprising, particularly since oxygen sags are commonly reported in studies of water quality effects of natural macrophyte die-back and also as a result of herbicide treatments. It is hypothesized that the difference is attributable to the fact that, during natural plant die-back and also after herbicide treatment, the plants undergo decomposition in the water column until sufficient decay has occurred for the plants to sink to the bottom. In the mechanical harvesting and disposal operation, plants are immediately cleared from the water column, resulting in improved water mixing. The finely chopped plant material that is

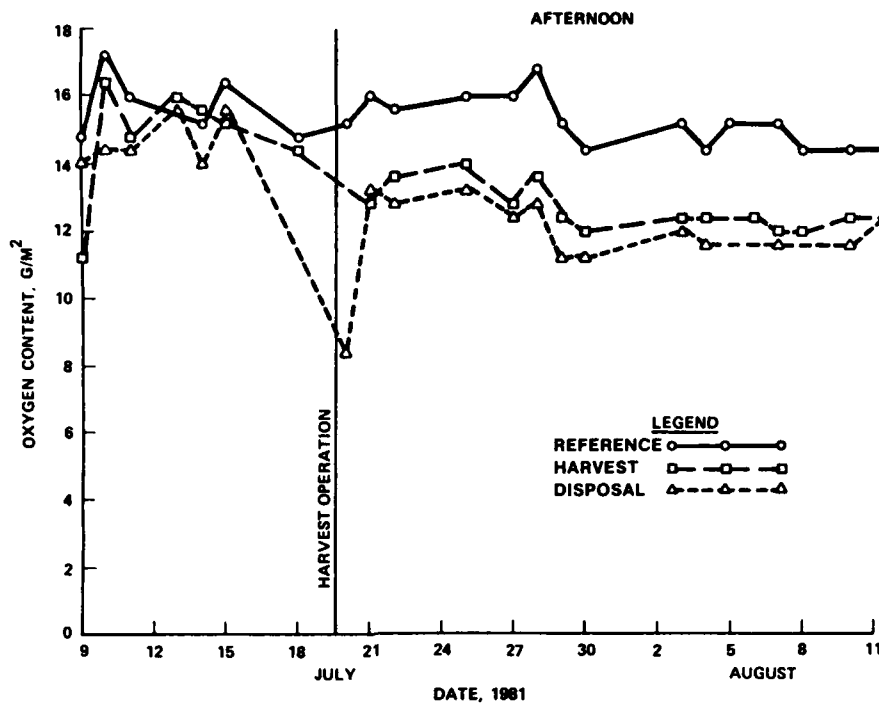


Figure 4. Mean afternoon dissolved oxygen content in test plots

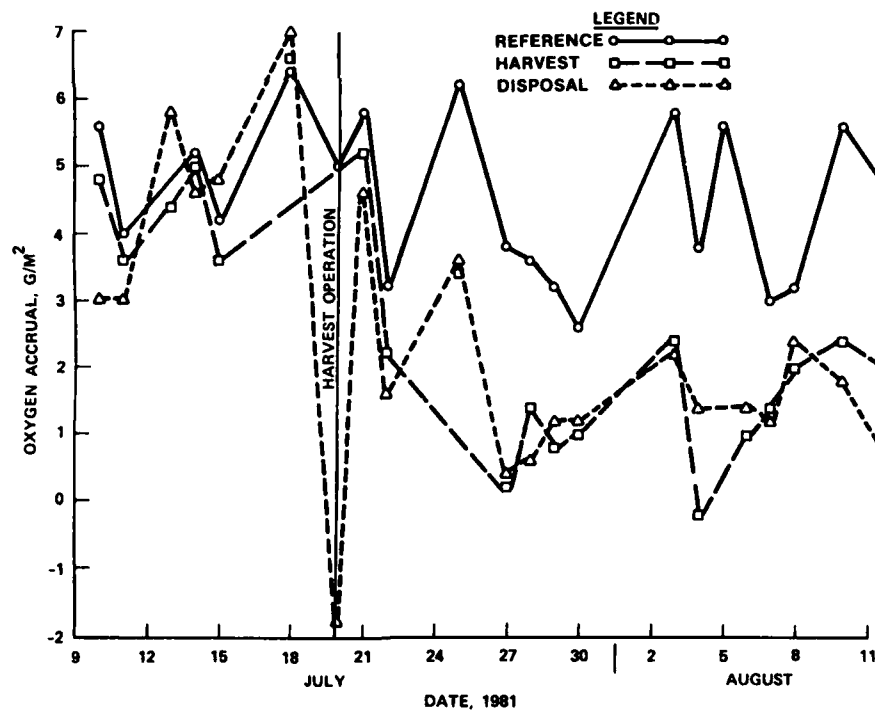


Figure 5. Mean daily accrual of dissolved oxygen in test plots

placed in the water during disposal settles immediately to the bottom; all decay and nutrient release, therefore, occurs from the bottom, resulting in less impact on the upper portion of the water column.

### Phytoplankton response

The trichromatic chlorophyll *a* concentrations, an indicator of phytoplankton density, are shown by plot and date in Figure 6. Mean chlorophyll *a* concentration in the disposal plot doubled after harvesting and disposal; concentrations in the harvest plot increased slightly over preharvesting concentrations; and concentrations in the reference plot decreased slightly. While there was a slight algal bloom due to disposal, it did not approach problem levels.

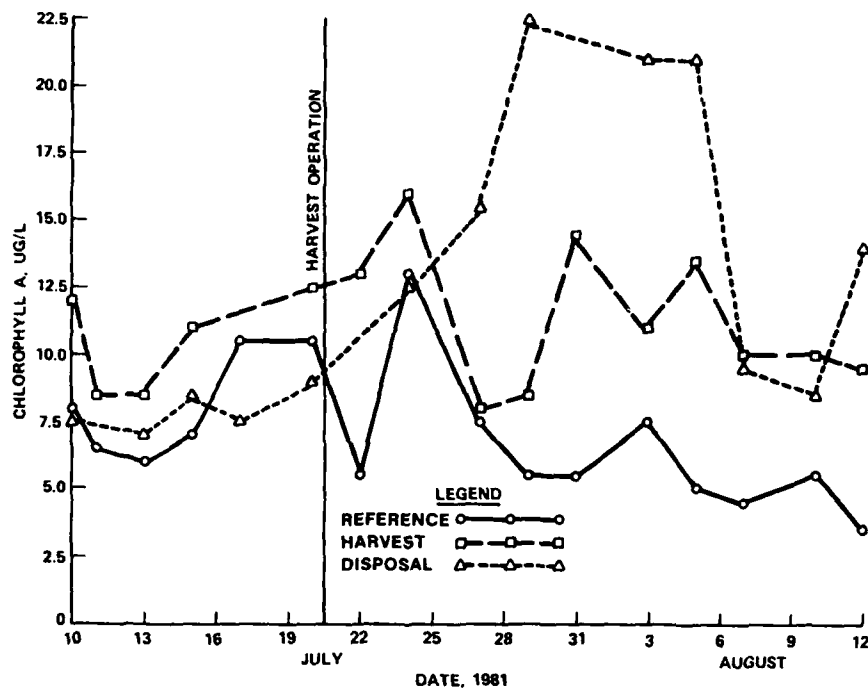


Figure 6. Mean chlorophyll *a* concentrations for test plots

### Fragment regrowth

After 3 weeks, all fragments in the in situ regrowth chambers had either decayed or showed new stems of growth. An average of 37 hydrilla fragments per kilogram of chopped material showed new growth. This represents only 0.6 percent of the total number of stem fragments placed in the water during disposal, but it can be an appreciable amount considering that 20 tons or more of plant material could be harvested from an acre of infested water body. It is noteworthy that the resproutable fragments tended to be the larger pieces that contained several nodes.

Results of the settling test showed that all leaf material sinks immediately, and most stem fragments sink in a matter of hours. The longest stem fragments tend to float for three days or more. Many of the fragments could therefore settle within the harvested area, and those with the greatest potential regrowth will float and could spread to other areas of the water body by wind or water currents. For a water body like Orange Lake, which is already completely infested, the spread of potentially viable fragments would be of minimal concern. In other water bodies, such as a partially infested lake or river, the potential exists for infestation of new areas; therefore, control operations should include methods for controlling dispersion of the fragments.

### **FUTURE RESEARCH**

The results of this field study showed that the water quality effects of the aquatic disposal of hydrilla were minimal. The feasibility of using this disposal practice, therefore, should be considered for water bodies infested with hydrilla and other species. To accomplish this, WES will develop a computer model to allow prediction of water quality occurring after disposal. Data from the Orange Lake study will be used to calibrate the model. Short-term field studies will be conducted under diverse environmental and operational conditions for verification of the model.

Future research will be conducted to provide for improved processors that can be used for mechanical control operations. Data on the characteristics of repropagatable plant fragments collected in this study will be used to help design a second-generation processor that will minimize the potential for regrowth of plant fragments.

# MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

## Simulation Modeling of Mechanical Control Systems

by  
Tommy D. Hutto\*

Analytical computer models that aid in the evaluation and design of existing or proposed mechanical systems for harvesting aquatic plants are an important part of the mechanical control work area of the Aquatic Plant Control Research Program (APCRP). The purpose of this paper is to identify factors that affect mechanical harvesting of aquatic plants, to describe the first-generation harvesting model HARVEST, and to demonstrate the applications of the model for predicting plant harvesting times and rates.

Performance predictions for two equipment mixes for each of three existing mechanical control systems are presented. Three environmental data sets representing different in situ densities of hydrilla as well as different distances from the harvesting site to the land disposal site were used as input to the HARVEST model.

### DESCRIPTION OF THE HARVEST MODEL

The first-generation mechanical control model is a simplistic deterministic model and is written in Fortran IV. Although the model will simulate the performance of most existing mechanical control systems, modifications are under way to make it more generalized and flexible. The ultimate objective is to provide a capability to predict total operational times and costs for harvesting an infested area, including simulating the effects of system deployment, maintenance, breakdowns, etc.

#### Model inputs

**Equipment inputs and characteristics.** The input values for the HARVEST model are shown in Table 1. The speed values shown are the maximum speed the various pieces of equipment can attain under actual harvesting operations. The two most important inputs are the maximum speed of the harvester and the harvester throughput. The latter value is a maximum average value and is very difficult to obtain for some machines. It represents the upper limit that, when reached in high plant densities, causes the harvester to reduce its forward speed. In low densities, this value, depending on the particular system, may not be attainable even when the harvester is operating at the maximum harvesting speed simply because the volume of plants needed is not available. Together, the two equipment input parameters control machine total productivity within a given plant density.

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\* U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

**Table 1**  
**Inputs to HARVEST Model**

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**Equipment characteristics:**

Cutter width, ft  
Harvester maximum speed, ft/min  
Harvester throughput, tons/hr  
Harvester turning time, min  
Transport unit changing time, min  
Transport unit capacity, tons  
Transport unit speed loaded, ft/min  
Transport unit speed empty, ft/min  
Unloading pumping rate of transport unit, tons/min

**Environmental parameters:**

Plant density grid array, tons/acre  
Water velocity, mph  
Water depth, ft

**Other inputs:**

Distance from site corner nearest disposal site to disposal site, ft  
Plot corner nearest disposal site  
Correction factor by which biomass sampler densities are multiplied  
Docking and setup time at disposal site, min

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***Environmental parameters.*** Plant density is one factor that determines the rate of movement of the equipment within the area to be harvested. The density values for a particular area are represented by a grid array with each grid point reflecting the plant density of that respective grid cell. This grid array is generated by digitizing an areal plant density map of the area and using a computer program to assign a plant density value to each grid point at some arbitrary grid spacing. The maximum plant density grid spacing is dependent upon the characteristics of the mechanical control system being evaluated; with the present system, a value of 2 ft is considered a good trade-off between machine performance and volume of data that has to be handled in the model.

***Other inputs.*** The minimum allowable harvesting speed is dependent on water velocity. For ponded water (zero velocity), the harvesting speed is presently set at 1/2 mph. It is the speed that when reached causes a change in harvesting procedure that will reduce the amount of material being harvested since the harvester cannot efficiently handle this material even at this minimum speed. This is done by reducing the harvesting width or depth. An empirical biomass factor is also used to correct the measured in situ densities within an area to values that correlate with densities that have been computed from the amount of plant material removed by a mechanical harvester. This empirical factor does not change the areal distribution of the measured plant densities. For example, if a grid point has a density of 20 tons/acre and another grid point has a density of 10 tons/acre and an empirical factor of 3 is used, the density value of 20 tons/acre is changed to 60 and the other to 30. Therefore, the magnitude of all density values is changed by the same percentage.

Other factors that affect the harvesting rate, such as distance to land disposal site, are used by the model and show the effects of limited number of transport units, slow transport unit speeds, etc.

### Model outputs

The HARVEST model outputs are shown below. The model keeps track of all the harvesting operation components on a swath-by-swath basis through the site and the average plant density encountered for each swath being harvested.

- Harvester speed for each swath, ft/min
- Harvester time for each swath, min
- Plant material harvested for each swath, tons
- x- and y-location of each filled transport unit in site
- Total harvesting time, min
- Total harvesting time including turning time, transport time, and disposal time, min
- Time harvester is waiting for transport unit, min
- Total areal production of system, acres/hr
- Average system productivity (throughput), tons/hr
- Total plant material harvested, tons

### Assumptions of the model

Although the model can be used as a management tool, a careful interpretation of the assumptions of the model (Table 2) is recommended.

Table 2  
Assumptions of HARVEST Model

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The cutter unit can operate at a faster speed than the harvester; i.e., it does not slow the harvesting operation.
The harvesting operation, which includes cutting, harvesting, transporting, and disposal, begins with the start of the harvester in the upper left corner of the site and ends when the last transport unit is emptied.
The turning time of the harvester at the end of the swath is constant.
The harvester operates at a constant speed for a particular swath. This speed is determined at the start of the swath and is based on cutter width, plant density, and maximum throughput of the harvester.
The transport units are filled to their rated capacity.
The transport units leave from the point at which they are filled, go through the site corner nearest the disposal site, and return through the site corner to the new location of the harvester in the site.
The loaded and unloaded speeds of the transport unit are constant as is the unloading (pumping) rate.
Docking and undocking times of the transport units from the harvester are constant.
The minimum forward speed of the harvester is an input, normally the current velocity or 0.5 mph, whichever is less.

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The most important assumptions of the model are:

- a. The harvesting operation is not limited by the cutter velocity; i.e., the cutter can always go at least as fast as the harvester. The cutter may have to slow down or adjust its cutting width or depth so as not to cut too much plant material that would overload the harvester or permit material to float away from the path of the harvester.
- b. The harvester's speed is controlled by the in situ plant density within a specified layer depth along the swath, and also by the maximum plant material throughput of the harvester. Previous models have assumed the maximum speed of the harvester and controlled the amount of material by varying only the cutting width of the plants. In the HARVEST model, a cutter width reduction only occurs when the harvester, because of increased plant density, has been slowed to a speed below the velocity of the water or some accepted minimum value if the water body has no current. There are some other factors that can limit the general prediction procedure of the model, such as equipment downtime. These are noted in the subsequent discussion of model predictions.

### Logic of the model

The program logic for the overall mechanical control operation is shown in Figure 1. The program first reads the equipment data base. Then, the environmental data base is accessed and the optimum harvesting condition (Option 1 in Figure 1), which is full cutter width and full cutter depth, is evaluated.

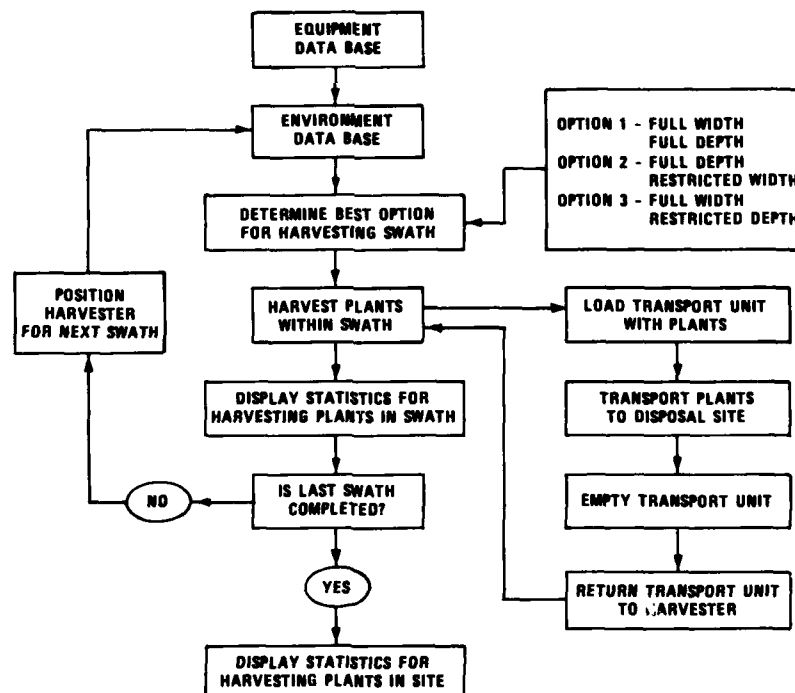


Figure 1. Generalized flowchart for HARVEST model

The average plant density for the swath is calculated from the density array for the maximum cutter width and depth. The harvester forward speed to maintain the maximum harvester throughput is then calculated. If the calculated speed falls between the maximum and minimum harvester speed inputs for the system, harvesting of the swath is then initiated. If this speed is greater than the maximum allowable harvester speed, the maximum speed is used for harvesting of the swath. If the harvester maximum speed controls the operation, this indicates that the aquatic plants are of a density that is too low to maintain the maximum throughput of the system even at the maximum operating speed. If the calculated speed is less than the harvester's minimum speed, then Option 2 is selected for evaluation. Option 2 allows full depth, but the cutting width of the plants can be reduced so as to increase the speed of the harvester. If the new calculated harvester speed is above the harvester's minimum speed, the swath can be harvested. If the speed is still not acceptable, the cutting width is reduced again until either an acceptable speed is reached or the cutter width reaches an unacceptable value, which is currently assumed to be 6 ft. If this occurs, Option 3 is evaluated, which allows decreasing the depth of cutting to minimize the amount of material to be harvested within the swath and maintaining full width.

The procedure is repeated for as many swaths as necessary to harvest the plot with transport units (or barges) being emptied as they are filled. It is believed that adjustment of the harvester speed due to changes in in situ plant density is a good assumption because a system cannot operate at maximum speed unless the plant density is low. It is believed that Options 2 and 3 would only be needed in predicting

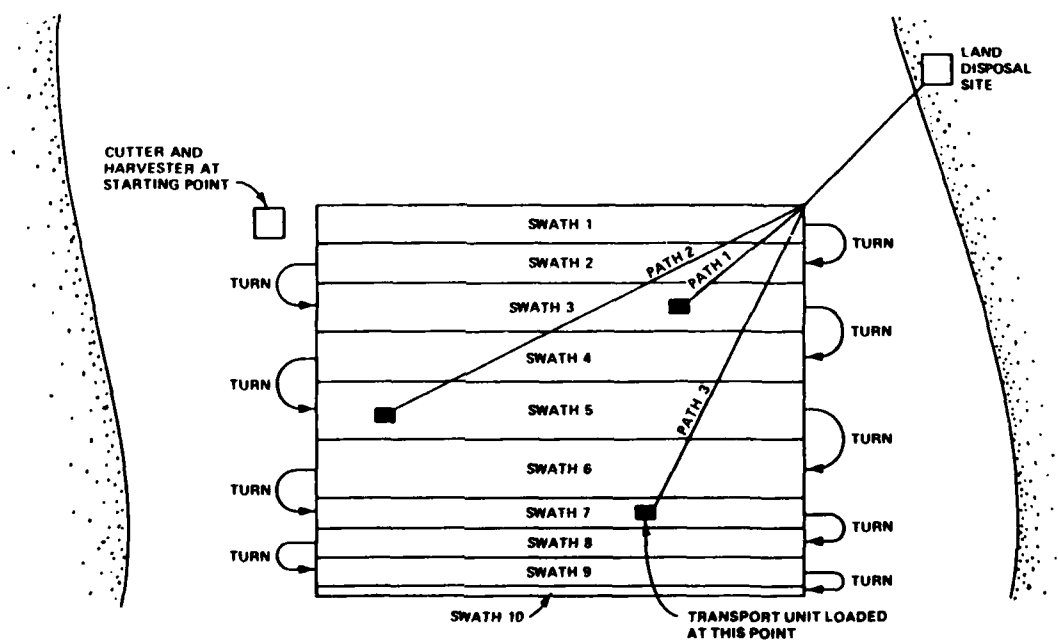


Figure 2. Sketch of cutting and harvesting simulation in HARVEST model

harvesting speeds for mechanical systems with extremely low throughput capabilities and for operation in very high density, submerged plant stands.

### **Simulations of actual cutting and harvesting operations**

The cutting and harvesting operation begins at any chosen corner of the site (Figure 2). At the end of the first swath, the harvester unit turns 180 deg, and harvesting continues along the next adjacent swath. This procedure continues until a transport unit is filled with plant material. Once filled, the harvester stops, disconnects the filled transport unit, and connects a new transport unit to the harvester. Harvesting then is reinitiated along the swath until the site is completed. Each x- and y-location where a transport unit is filled is determined from the grid array and is used to calculate transport time to and from the land disposal site. Once the transport unit has arrived at the land disposal site, it is docked and the time for unloading the material from the transport unit is determined. Once unloaded, the transport unit then travels back to the corner of the harvesting site nearest the disposal area and waits until another transport unit is filled with plant material.

## **MODEL PREDICTIONS**

Performance predictions for total plant harvesting time, harvester utilization, and average system productivity were obtained recently with the HARVEST model for three different mechanical control systems using two equipment mixes for each system. Total plant harvesting time is the lapsed time from the beginning of the site harvesting operation until the area is completely harvested and the last transport unit is emptied at the land disposal site. Harvester utilization is the percent of the total time the harvester is actually used to remove plants from the water; i.e., it does not include waiting time or downtime for equipment repair. Average system productivity is calculated by dividing the total plant material harvested by the total harvesting time which gives the system productivity (tons/hour).

The predictions were made to demonstrate the simulation capability of the model and not as an absolute comparison of the three mechanical systems. Factors such as initial capital cost, depreciation, maintenance, frequency and cost of breakdowns, and deployment opportunity were not considered since realistic data to support such a comparison were not available. Also, some of the important equipment parameters for the systems were not available and estimates of these parameters had to be obtained without field verification. Predictions of the cost for plant harvesting are discussed in terms of the cost of labor and fuel for the predicted harvesting time.

### **Equipment mixes**

The equipment mixes for the three mechanical harvesting systems are shown in the tabulation below.

<i>Harvesting System</i>	<i>Mix 1</i>	<i>Mix 2</i>
A	1 Cutter-Harvester Combination* 1 On-Shore Conveyor	1 Cutter Harvester Combination** 2 Transports 1 On-Shore Conveyor
B	1 Cutter 1 Harvester** 1 Transport	1 Cutter 1 Harvester** 2 Transports
C	1 Cutter-Harvester Combination* 1 On-Shore Conveyor	2 Cutter-Harvester Combinations* 1 On-Shore Conveyor

\* Harvester(s) is used for transport.

\*\* Harvester is not used for transport.

All of the harvesters in mix 1 are assumed to be idle as far as harvesting is concerned when the transport unit is filled to capacity. Systems A and C both use the harvesters as transport units for land disposal operations. The cutter and harvester of System B are considered idle while the one transport unit is carrying a load of material to the land disposal site. The cutter and harvester units of System B have no transport capability. In mix 2 the harvesters for Systems A and B are not used as transporters while the two harvesters of System C are both used as transporters so there are periods when both harvesters of System C are transporting plant material to the land disposal site.

### Equipment inputs

The equipment parameters for the three systems that are input to the HARVEST model are shown below.

<i>Equipment Parameters</i>	<i>Harvesting System</i>		
	<i>A</i>	<i>B</i>	<i>C</i>
Harvesting speed (Max), ft/min	176	220	176
Cutting width, ft	8	18	8
Harvester throughput, tons/hr (Max Avg)	15	30	9
Harvester turning time, min	1.5	1.5	1.5
Transport changing time, min	2.0	5	NA
Transport capacity, tons	3.53	15	3.53
Loaded speed of transport, ft/min	400	400	528
Empty speed of transport, ft/min	450	600	528
Unloading rate of transport, tons/min	1.0	1.0	2.2
Docking time, min	3.0	6.0	3.0

The four most important parameters are maximum harvesting speed, cutting width, harvester throughput or the maximum average amount of material that can be removed per hour, and plant holding capacity of the transport units. The parameter values for Systems A and C are estimates and were primarily obtained from manufacturer's specifications. However, field tests have been conducted by the U.S. Army Engineer Waterways Experiment Station (WES) with System A and some data have resulted from these tests.

Comparison of the above parameter values shows that: the maximum harvesting speeds of the system are roughly the same; the cutting width of System B is more than

double that of the other two systems; System B's maximum throughput is approximately two to three times that of either of the other two systems; and System B has roughly four times the plant holding and transport capacity. All other values are approximately the same for all three systems. The effects of these parameter values are discussed in this paper.

### **Environmental inputs**

The primary environmental parameter is *in situ* plant density (tons/acre) and is represented by a plant density grid array that has a 2-ft grid spacing. The harvesting site dimensions are 250 m by 1000 m, which represents a 5.05-acre plot. The plant species is hydrilla and the densities for the 0- to 2-ft depth layer represent two plant density conditions (12 to 27 tons/acre and 4 to 9 tons/acre, respectively) and two different distances (1/2 mile and 1 mile, respectively) from the harvesting site to the land disposal site. The three unique data sets used for the predictions are shown below:

- |             |  |
|-------------|--|
| Data Set 1: | Plant Density - 12 to 27 tons/acre<br>Distance to Disposal Site - 1 mile   |
| Data Set 2: | Plant Density - 12 to 27 tons/acre<br>Distance to Disposal Site - 1/2 mile |
| Data Set 3: | Plant Density - 4 to 9 tons/acre<br>Distance to Disposal Site - 1 mile     |

## **ANALYSIS OF PREDICTIONS**

The predictions for the three systems were analyzed to show the effect of equipment mix, distance to the disposal site, and plant density on total harvesting time, harvester utilization, and average system productivity. Predictions using data set 1 were analyzed to show the effect of different equipment mixes, i.e. equipment mix 1 and 2 for each system. Predictions using data sets 1 and 2 and equipment mix 2 were analyzed to show the effect of different distances to the disposal site, i.e. 1 mile (data set 1) and 1/2 mile (data set 2). Predictions using data sets 1 and 3 and equipment mix 2 were analyzed to show the effect of different plant densities, i.e. 12 to 27 tons/acre and 4 to 9 tons/acre. Additional predictions using data set 1 were analyzed for System B to show the effect on harvesting time and fuel and labor costs for both water disposal and land disposal operations.

System B was the only system that had the capability to chop the plants so that subsequent water disposal could be considered within a given control operation.

### **Effects of equipment mix**

The effects of additional system components on total harvesting time, harvester utilization, and average system productivity are discussed in the following paragraphs.

**Total harvesting time.** The effect of equipment mix on harvesting time is shown in Figure 3. The results show that adding two transport units (equipment

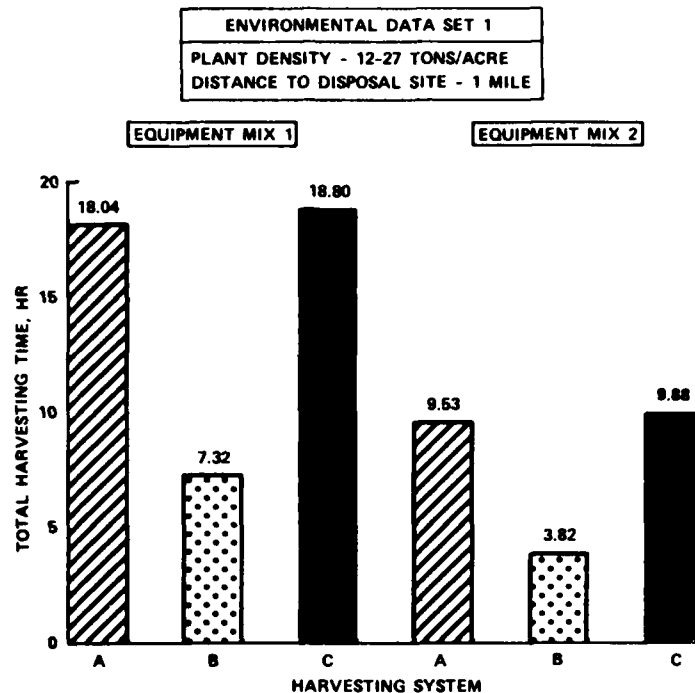


Figure 3. Effects of equipment mix on total harvesting time

mix 2) to System A decreases the site harvesting time by 8.51 hr (47 percent). Adding one additional transport unit to System B reduces its total site harvesting time by 3.5 hr (48 percent). Adding an additional harvester to System C reduces its site harvesting time by 8.92 hr (47 percent). The reductions in time for harvesting the 5.05-acre site are considered reasonable. Although predictions were not obtained with other equipment mixes for Systems A and B by adding additional transport units or with System C by adding more harvesters, it is considered reasonable to assume that adding more transport units to Systems A and B would eventually result in no further time reductions since the additional transport units would be idle while waiting on the harvester to fill one of the other transports. The time for harvesting the site using System C would continue to decrease as more harvesters were added since the harvesters are used as transports. The final determination of the optimum equipment mix for a particular control operation must be based on the existing plant density and the distance to the land disposal site. Also, the determination of which mix is optimum is constrained by time and cost; i.e., a mix is optimum only if it falls within these allowable constraints. Therefore, the outputs from the HARVEST model can only be used to give the operations manager a choice of equipment mixes with the predicted harvesting time for each component.

**Harvester utilization.** The effect of equipment mix on harvester utilization is shown in Figure 4. The results show that utilization of the harvester for System A

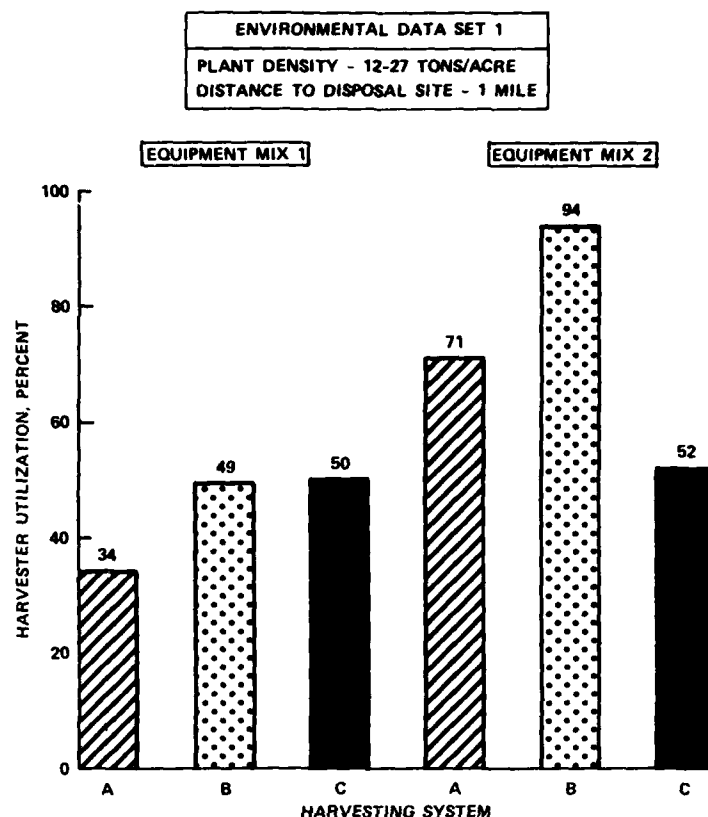


Figure 4. Effects of equipment mix on harvester utilization

increased by 37 percent and System B by 45 percent by the addition of another transport unit. The additional transport units for A and B allowed their harvesters to be used for a longer time during the site harvesting operation. Harvester utilization remained about the same for System C by adding an additional harvester. This resulted from the fact that the harvesters must stop during the harvesting operation when loaded and must then transport the plant material to the land disposal site. Of course, the most cost-effective operation would be to utilize the harvester near 100 percent of the operational time. This would only occur when or if there were enough transports available to keep the harvester operating continuously. The optimum number of transport units depends on the in situ plant density and on the distance to the land disposal site. System B shows a utilization of 94 percent with mix 2 (two transports), which approaches the optimum control operation. If an additional transport unit were added, the harvester utilization would approach 100 percent but transport unit utilization would drop below 100 percent. Consequently, the addition of another transport is not needed. The nearer the land disposal site, the higher the utilization that would be attained by Systems A and C, with System C's harvester utilization being more sensitive to the distance

since the harvester itself is being used to transport the material to the disposal site. The primary reasons for the lower utilization by Systems A and C for either mix is simply that these systems have low transport capacities and the harvesters are not being utilized during the transport and disposal part of the control operation.

**Average system productivity.** The effect of equipment mix on average system productivity is shown in Figure 5. These results show increases in productivity of 88 percent (3.8 tons/hr), 91 percent (9.6 tons/hr), and 88 percent (3.6 tons/hr) for Systems A, B, and C, respectively, as a result of changing from mix 1 to mix 2. This is understandable since the productivity is a function of total harvesting time. As stated earlier, adding more transport units, but no harvesters, to Systems A and B reduces harvesting time and increases system productivity. The point after which more transport units do not increase productivity is primarily a function of plant density and distance to the disposal site. Of course, equipment mixes made by adding more harvesters to Systems A and B will increase productivity but also will result in higher capital and operating costs. Whether this is feasible or not will depend on the time available to harvest the plot and the funds available for equipment purchases and harvesting operation. Productivity of System C will increase as additional harvesters are added, but so will capital costs for the harvesters, and yet the harvesters individually maintain the same productivity and will be utilized at less than maximum. The use of separate transport units would definitely improve System C's productivity and certainly be less costly than purchasing additional harvesters that are currently used also as transport units.

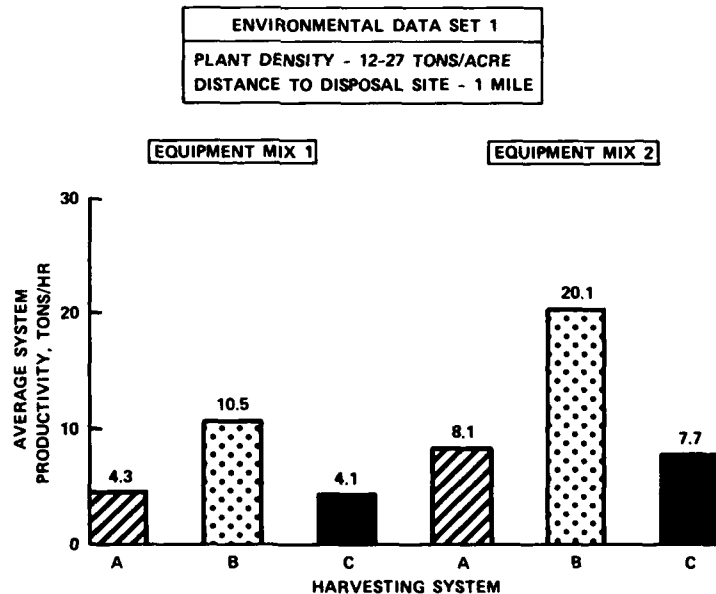


Figure 5. Effects of equipment mix on average system productivity

### Distance to disposal site

The effect of different distances to the land disposal site on the three harvesting parameters is discussed below using two distances, 1 and 1/2 mile, and equipment mix 2 for each of the three mechanical systems.

**Total harvesting time.** The change in the distance from the harvesting site to the land disposal site from 1 to 1/2 mile shows total harvesting time decreasing by 2.18 hr (23 percent), 0.32 hr (8 percent), and 1.75 hr (18 percent) for Systems A, B, and C, respectively (Figure 6). Systems A and C show greater savings in harvesting time than System B because they have lower transport capacities than System B. Since Systems A and C make more trips to the land disposal site, the distance to the land disposal site results in more harvesting time for both Systems A and C. From the predictions, it appears that the harvester in System B spends about the same amount of time waiting for a transport unit regardless of whether the distance to the disposal site is 1 mile or 1/2 mile. The waiting time at the harvester of System A is decreased more drastically with the shorter disposal distance. The effect of harvesting time when using the harvesters with System C is less than A but greater than B.

**Harvester utilization.** Predictions shown in Figure 7 show that decreasing the distance to the land disposal site increased the harvester utilization 20 and 10 percent, respectively, for Systems A and C and only 6 percent for System B. This indicates that the harvester of System B was utilized 94 percent with a 1-mile disposal distance and 100 percent under the same plant densities and a 1/2-mile disposal distance and will continue to operate at this level at any disposal distance less than 1/2 mile, although utilization of the transport units will decrease with a decrease in distance to the disposal site. System A showed a 20 percent increase in harvester utilization when the disposal distance was reduced to 1/2 mile. The distance to the disposal site must be very small for the harvesters of System C to even approach a 90 percent utilization and they will never reach 100 percent utilization due to their additional transport tasks.

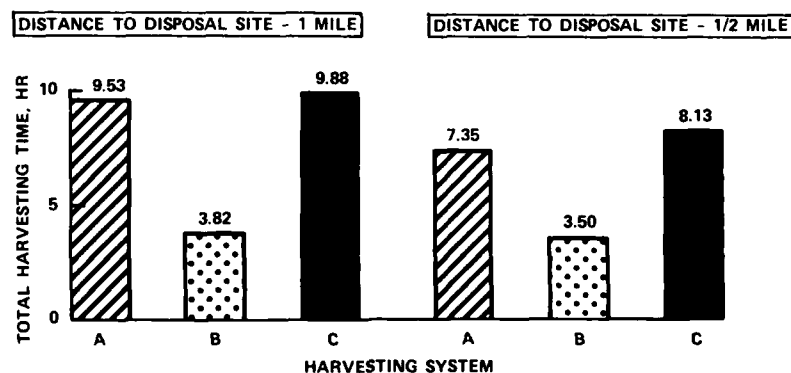


Figure 6. Effects of distance to disposal site on total harvesting time

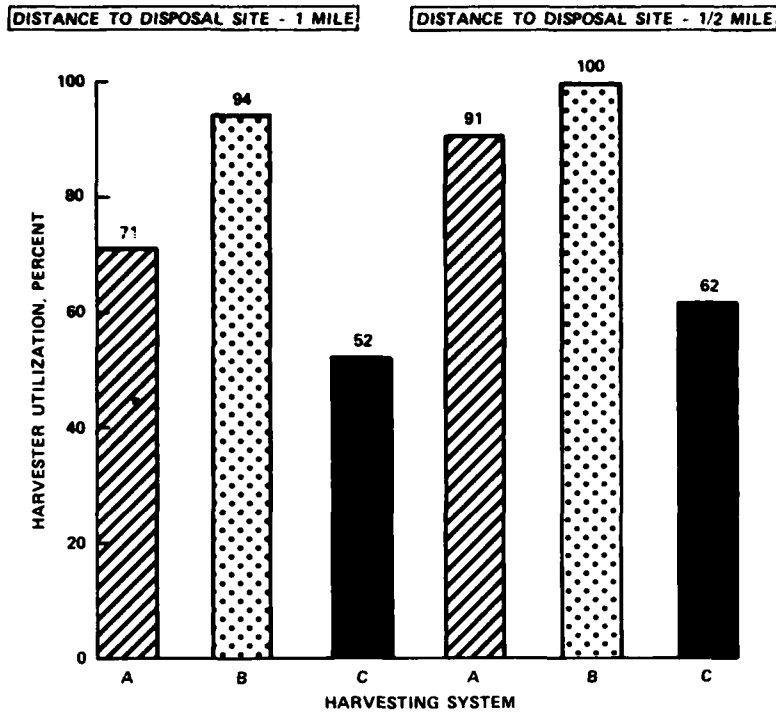


Figure 7. Effects of distance to disposal site on harvester utilization

**Average system productivity.** Predictions for average system productivity (Figure 8) showed increases of 30 percent (2.4 tons/hr), 9 percent (1.9 tons/hr), and 16 percent (1.2 tons/hr) as a result of decreasing the distance to the disposal site

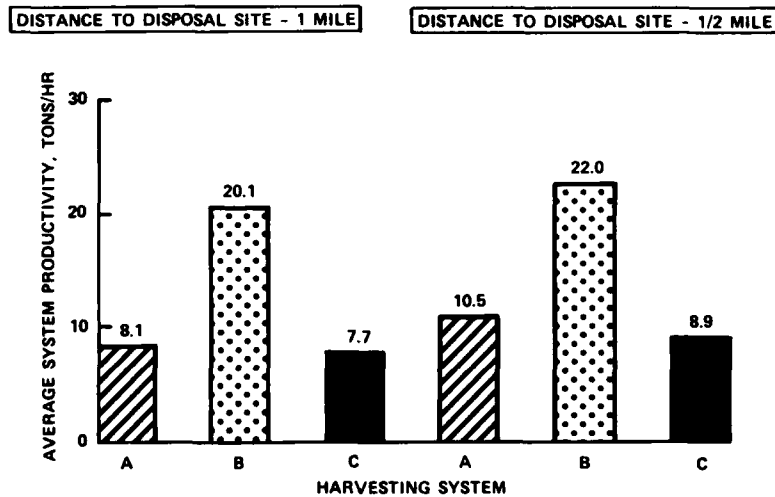


Figure 8. Effects of distance to disposal site on average system productivity

from 1 to 1/2 mile for Systems A, B, and C, respectively. Systems A and C, as stated earlier, are more sensitive to disposal distance than System B because they have very limited transport capacities and therefore must make more trips to the disposal site during the control operation.

### Effects of plant density

The effects of different in situ aquatic plant densities on the three HARVEST mechanical control output parameters are discussed in the following paragraphs. Equipment mix 2 was used as a basis for the predictions.

**Total harvesting time.** Predictions obtained for total harvesting time for two plant density conditions are shown in Figure 9. Changes in plant density from 12 to 27 tons/acre to 4 to 9 tons/acre caused a decrease in harvesting times of 5.32 hr (56 percent), 1.94 hr (51 percent), and 6.12 hr (62 percent) for Systems A, B, and C, respectively. System B was the least affected by the changing density because it had both a higher transport capacity and could remove more plant material per unit time than the other two mechanical systems. Systems A and C operate more efficiently in the lower densities because their maximum system throughputs are much lower than System B. The harvester of System B operates at maximum harvesting speed in the 4- to 9-tons/acre density, but also at a speed only slightly below maximum in the 12- to 27-tons/acre density. The other two Systems, A and C, operate at maximum speeds in the lower densities.

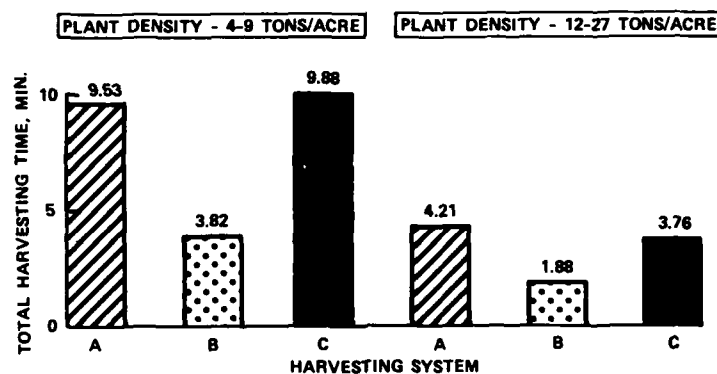


Figure 9. Effects of plant density on total harvesting time

**Harvester utilization.** Predictions for harvester utilization for the two plant density conditions are shown in Figure 10. Harvester utilization increased by 20, 6, and 11 percent for Systems A, B, and C, respectively, when the density was reduced from 12 to 27 tons/acre to 4 to 9 tons/acre. Again, the lower plant density had more effect on the higher productivity system, B, since it was already nearly at maximum utilization when operating in the higher density of 12 to 27 tons/acre. The harvester utilization of System A showed the greatest increase (from 71 to 91

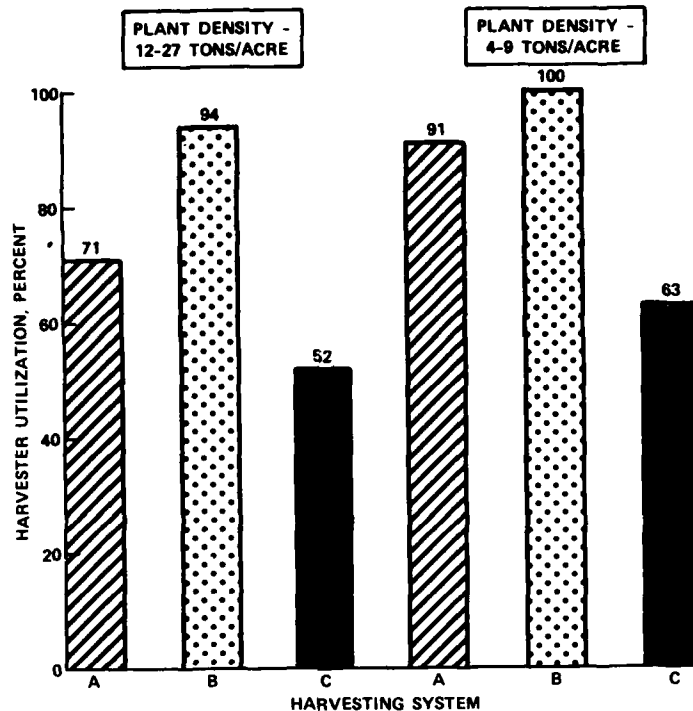


Figure 10. Effects of plant density on harvester utilization

percent). This increase resulted from the fact that the transport units had ample time to return from the disposal site to the harvester before the previous transport unit was filled to capacity, thereby reducing the harvester's waiting time and resulting in increased utilization of the harvester. Although the lower plant density (4 to 9 tons/acre) resulted in increased utilization for System C, it is still somewhat limited because the harvesters are also used as transport units, which means that part of their time is spent on transport and disposal duties.

**Average system productivity.** Predictions for average system productivity for the two plant density conditions are shown in Figure 11. These predictions show decreases in system productivity when the plant densities change from 12 to 27 tons/acre to 4 to 9 tons/acre of 2 tons/hr (25 percent), 6.4 tons/hr (35 percent), and 0.9 tons/hr (12 percent) for the three systems, respectively. Again, these reductions in system productivity affect System B more than either A or C because it has a higher system throughput and cannot operate at this maximum throughput in lower plant densities. The small changes in system productivity for Systems A and C are due to the fact that they are now operating at their maximum capacities in the lower densities.

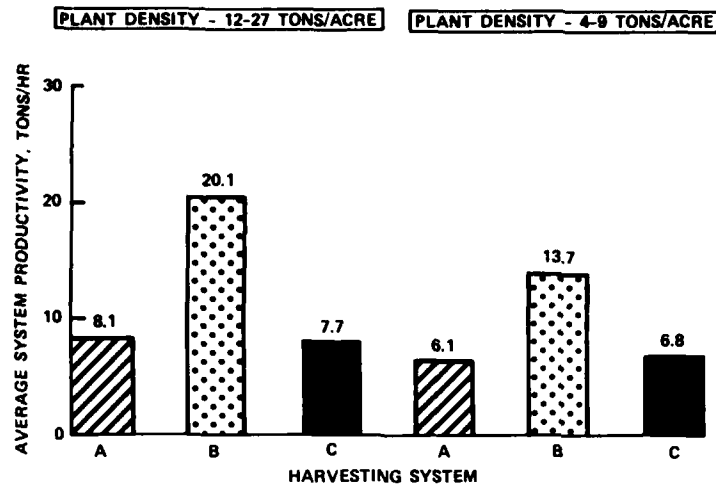


Figure 11. Effects of plant density on average system productivity

### PREDICTIONS USING LAND AND WATER DISPOSAL OPTIONS FOR CONTROL OPERATIONS

As stated earlier, model predictions were made using System B to determine the effects of using both water disposal and land disposal options. Predictions were obtained for total harvesting time and used to compute the labor and fuel costs for the land and water disposal options. The predicted harvesting times and subsequent costs for labor and fuel for the harvesting of the 5.05-acre plot are based on several assumptions. Only the relative difference in the times and subsequent costs for the two disposal conditions have been emphasized. The predictions are based on 100 percent plant removal efficiency from the harvesting site, with capital, machine, deployment, and maintenance costs, and downtimes for breakdowns and inclement weather considered the same. The calculated costs are based on arbitrary labor costs of \$12/hr and fuel costs of \$1.50/gal.

Predictions for harvesting times and the cost calculations for labor, fuel, and combined labor and fuel are presented in Figure 12. The predictions show that the total harvesting time was reduced from 3.82 to 2.86 hr, a reduction of 25 percent, by using water disposal as opposed to land disposal. Labor costs were reduced significantly from \$229 for land disposal to \$69 for water disposal, a decrease of about 70 percent. This change is due to the reduction in the number of people needed from five for land disposal to only two for water disposal. Fuel costs were reduced from \$29 to \$21, about 28 percent, when the two transport units were not used for the control operation. Total fuel and labor costs were reduced from \$258 to \$89, a reduction of 65 percent, with the major reduction in cost resulting from less labor being required for the control operation. In summary, these predictions indicate that significant cost reductions are possible if water disposal of processed plants can be used during a control operation. However, it is noteworthy that returning

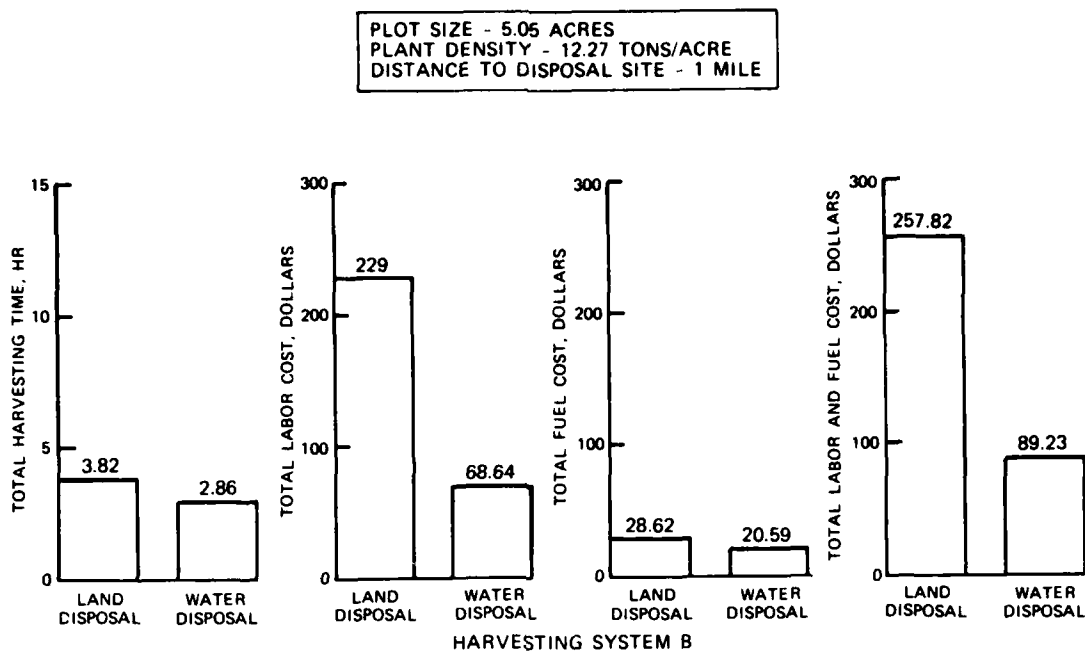


Figure 12. Harvesting times and fuel and labor costs for land and water disposal of processed plants for a 5.05-acre plot

processed aquatic plant material to the water during a water disposal operation may result in the possibility of new plant infestations in the water body unless the plant fragments are unviable and not capable of regrowth. Research at WES is under way to determine the effects of fragment regrowth and to develop onboard processors that minimize plant fragment regrowth. However, it is noteworthy that the study of the present submerged aquatic plant infestations indicates that effective mechanical processors should be designed to allow water disposal of the processed plants since about 65 percent of today's mechanical harvesting operations' cost is due solely to the transport and disposal operation.

## SUMMARY

The HARVEST model predictions demonstrate that the model is a useful tool in the evaluation of the effects on harvesting of different equipment mixes and environmental conditions for both existing or proposed systems. As demonstrated by the predictions, the extent to which the performance of these systems is affected by the varying conditions depends largely on the physical limitations of the mechanical systems.

## **PLANS FOR FY 82**

Efforts in FY 82 will be continued toward the development of the overall conceptual model for simulation of mechanical control operations. HARVEST will be made more user-oriented and flexible. A broader cost routine will be added, along with considerations for simulation of maintenance and breakdown frequencies and costs.

# CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

## An Overview

by  
Howard E. Westerdahl\*

## BACKGROUND

The primary objective of this work area is to seek and eventually make available new, safer herbicide formulations and better application techniques. This objective is being achieved through contracts with selected developers; efficacy evaluation of new chemicals by the U.S. Department of Agriculture (USDA) Aquatic Plant Management Laboratory (APML) in Fort Lauderdale, Fla., and Bureau of Reclamation in Denver, Colo.; and limited field and laboratory studies by U.S. Army Engineer Waterways Experiment Stations (WES) personnel. Particular emphasis has been placed on the development and evaluation of controlled-release herbicide formulations in which registered chemicals are primarily used. Dr. Frank Harris, Wright State University, will describe his progress in preparing a controlled-release 2,4-D formulation in a later paper. Moreover, efforts are continuing to isolate and identify naturally occurring chemical inhibitors to plant growth. Dr. Dean Martin, University of South Florida, will discuss the progress he has made in identifying a hydrilla inhibitor.

Approximately 12 controlled-release formulations have been developed over the past several years, of which two 2,4-D formulations have been found to have significant potential. Concerning these formulations, Dr. Thai Vann, USDA-APML, and Mr. Ron Hoeppel, WES, will discuss results from laboratory and field tests, respectively. In March 1981, a WES Information Exchange Bulletin article was published describing the cooperative herbicide evaluation program with the USDA-APML. This program permits herbicide developers to submit their formulations for efficacy evaluations against a variety of aquatic macrophytes at no charge. An interagency agreement was approved with the Bureau of Reclamation in Denver to permit the evaluation for use in irrigation systems of controlled-release formulations developed at WES under contract.

Continued Corps interest in controlled-release herbicide formulations has prompted several companies to explore controlled-release concepts with the idea of improving their chemical's performance. Currently, the WES is working with Chevron, Duphar, Elanco, Pennwalt, and Union Carbide in efforts to evaluate their formulations for use in controlled-release systems.

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\*U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

## IN-HOUSE RESEARCH

Complementary to ongoing work at the USDA-APML, a laboratory diluter system was developed at WES for determining the minimum sustained herbicide concentration in water required to control select aquatic plants (Figure 1). This system delivers several different concentrations of a specific herbicide to 24 aquaria. Each herbicide concentration is maintained in four aquaria. The automatic and reliable production and maintenance of prescribed herbicide dilutions permits testing of selected herbicides against specific aquatic macrophytes.

The following description and reference to Figure 1 will clarify the basic components of the diluter system and their function. The Data Trak controller (1) is a programmable microprocessor which controls virtually all of the key components

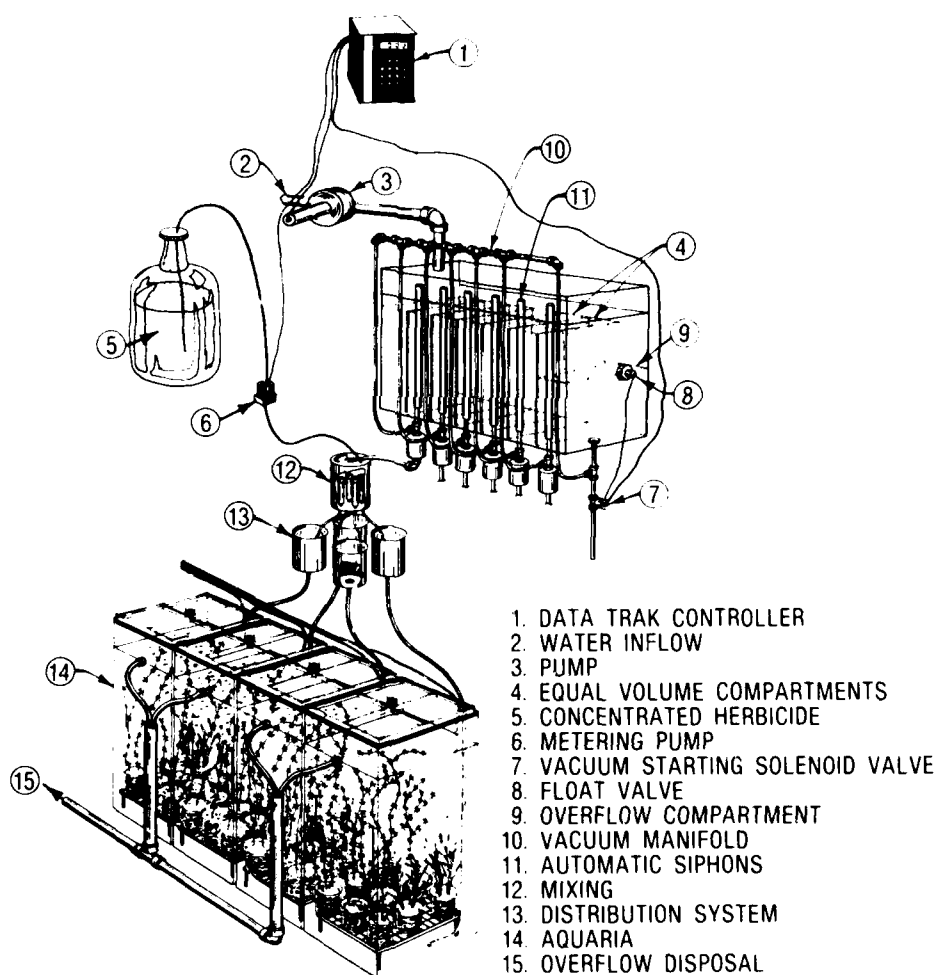


Figure 1. Schematic of the diluter system

of the system. Moreover, the diluter system is operated via a 24-v direct current power supply, thereby being unaffected by power interruptions to the facility. The influent water (2) is pumped (3) from a stainless steel tank to the acrylic compartmented chamber (4). Following the filling of each compartment, selected quantities of the concentrated herbicide solution (5) are pumped, using Valcor, Inc., SV-500 series metering pumps (6), to the mixing chamber (12). The vacuum-starting solenoid valve (7) is opened via an electrical impulse from the float valve (8) when the overflow compartment (9) is filled. This allows water from the overflow compartment to drain and thereby exert a reduced pressure on the vacuum manifold (10) and siphon locks (11), which causes the water within each compartment (4) to be pulled up and over the outlet of each automatic siphon. The siphon breaks after each compartment empties and the water from each compartment flows into a 4-l stainless steel mixing chamber (12). The previously added concentrated herbicide is completely mixed by the inflowing water to this can. Four automatic siphons within each mixing chamber operate simultaneously when the can (12) fills with water. The desired herbicide dilution flows out of the overflow siphons into four 1-l stainless steel cans comprising the distribution system (13). The desired herbicide dilution proceeds to each aquarium (14), respectively, via gravity flow out of these containers. Currently, the modified diluter system is capable of delivering water volumes of 1 l to each of the 24 glass aquaria which, with an overflow located on the site to maintain a water volume of 50 l, are 76 cm high by 30 cm long by 30 cm wide.

The entire cycle repeats every 30 min for a designated time period. Longer cycle times can be programmed into the Data Trak controller. Likewise, the amount of concentrated herbicide added to the mixing cans can be varied by programming the desired number of pumping strokes into the Data Trak controller; however, adequate recycling time for the system must be allowed.

Herbicide solution enters each of the aquaria at the bottom and is circulated throughout by a pumping action created by bubbling air up an acrylic standpipe 30 cm long and 1.7 cm in diameter. Air is injected through an air stone diffuser at the bottom of the standpipe, causing water and the injected herbicide solution to be circulated up through the standpipe. Continuous recirculation of water up the standpipe ensures thorough herbicide mixing in each aquarium, based on preliminary dye studies. Overflow from each aquarium is passed through a carbon absorption tank to remove the residual herbicide prior to disposal (15).

The herbicide, 2,4-D, was tested against Eurasian watermilfoil (*Myriophyllum spicatum*) and Sago pondweed (*Potamogeton pectinatus*). A 6-week pilot study\* showed that the diluter system operated within design specifications. Moreover, the data suggested that the minimum sustained 2,4-D concentrations required to control *M. spicatum* and *P. pectinatus* were 0.04 to 0.10 mg/l and approximately

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\* Westerdahl, H. E., et al., "Estimation of the 2,4-D Threshold Concentration for Controlling Select Aquatic Macrophytes - Pilot Study," Technical Report (in preparation), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

0.20 mg/l, respectively. A follow-up study of approximately 12-weeks duration verified results obtained during the pilot study.\* Most significant, however, is that the sustained 2,4-D acid concentration required to control *M. spicatum* was less than the 2,4-D Federal tolerance (0.10 mg/l) for potable water, i.e., 0.05 to 0.10 mg/l. Herbicide delivery systems that will make available to the treated water column the recommended sustained 2,4-D concentration should minimize adverse environmental impacts by eliminating the need for high initial herbicide concentrations to control aquatic plants.

### FUTURE RESEARCH

During 1982, we will use the aforementioned diluter system to determine the minimum sustained fluridone and dichlobenil concentrations required to control *M. spicatum* and *Hydrilla verticillata*. Secondly, a contract was recently approved with Southern Research Institute in Birmingham, Ala., to develop controlled-release fluridone and dichlobenil formulations during FY 82 and FY 83.

The University of South Florida will continue their attempt to identify the chemical structure of the naturally occurring hydrilla inhibitor. We will continue laboratory and field evaluation of improved controlled-release 2,4-D formulations and, in FY 83, we will determine if any additional registration requirements for these formulations are required by the U.S. Environmental Protection Agency (EPA). Finally, a Herbicide Users Guide will be considered for preparation and publication in FY 83. Through close coordination with the Registration Division of the EPA in Washington, D.C., updated information on herbicide registration status will be obtained and made available to Corps Districts.

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\* Hall, J. F., et al., "The 2,4-D Threshold Concentrations for Control of Eurasian Watermilfoil and Sago Pondweed," Technical Report (in preparation), U.S. Army Engineer Waterways Experiment Station, CE Vicksburg, Miss.

# **CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT**

## **Evaluating Controlled Release Herbicides for Aquatic Weed Control**

by  
Thai K. Van\* and Kerry K. Steward\*

### **INTRODUCTION**

Several recently developed techniques of formulating selected chemicals within various polymers or matrix structures to provide controlled release over time appear to hold great potential for safer long-term management of nuisance aquatic plant growths.

A protocol for evaluating this potential has been developed and involves determinations of: (1) chemical release rates; (2) stability of the released chemicals (degradation rate); (3) constancy of chemical release from the formulation (reliability); and (4) efficacy of the formulation in managing or eliminating aquatic plant growths. All four of the above evaluation phases are initially conducted in the laboratory. Confirmation of findings from the last two phases are attempted in outdoor studies conducted in large aquaria under environmental conditions more closely approximating those in the field.

The major emphasis of our investigations in this project has been to implement the protocol for evaluating various controlled-release herbicide formulations (CRHF).

Of the several CRHF evaluated in our laboratory this past year, two experimental CR 2,4-D formulations were further tested by the Corps under field conditions in Lake Seminole last April. This report summarizes the results of our laboratory evaluations of these two formulations, namely Poly (GMA) 2,4-D in clay pellets and 2,4-D acid in pelletized Kraft lignin residue. The Poly (GMA) 2,4-D (10 percent a.i.\*\*) was developed by Wright State University, Dayton, Ohio, and the 2,4-D acid/lignin product (50 percent a.i.) was supplied by Westvaco, Inc., North Charleston, South Carolina.

### **RELEASE RATES OF 2,4-D**

#### **Clay pellet Poly (GMA) 2,4-D in static reconstituted and natural water**

Release of 2,4-D from clay pellets Poly (GMA) 2,4-D was determined first in static water tests under controlled laboratory conditions at  $28^{\circ} \pm 2^{\circ}\text{C}$ . Treatments of the

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\* Aquatic Plant Management Laboratory, U.S. Department of Agriculture, Fort Lauderdale, Florida.

\*\* a.i. = active ingredient.

clay pellets were made to 3.7 l of water with amounts calculated to produce a concentration of 0.1 mg/l 2,4-D every 24 hr.

Natural water from a dug pond on the Fort Lauderdale Agricultural Research Center grounds was used. Water quality was monitored monthly; these data are presented in Table 1. For interlaboratory comparisons, release rate data were also determined in reconstituted distilled water, pH 8.0, containing 192 mg NaHCO<sub>3</sub>, 120 mg CaSO<sub>4</sub> · 2H<sub>2</sub>O, 120 mg MgSO<sub>4</sub>, 8 mg KCl per litre.

**Table 1**  
**Water Quality Control Analysis**

<i>Date</i>	<i>Oxygen ppm</i>	<i>Conductivity μmhos</i>	<i>pH</i>	<i>Alkalinity mg/l CaCO<sub>3</sub></i>	<i>Hardness mg/l CaCO<sub>3</sub></i>	<i>Temperature, °C</i>	
						<i>Air</i>	<i>Water</i>
Mar 81	8.19	410	7.59	147.4	176.7	22.8	25.0
Jun 81	6.43	331	7.96	149.9	174.8	26.4	28.2
Sep 81	5.86	318	7.41	144.4	179.9	24.9	27.4

<i>Date</i>	<i>Phosphate mg/l</i>	<i>Nitrate mg/l</i>	<i>Ammonia mg/l</i>	<i>Solids, mg/l</i>	
				<i>Total</i>	<i>Suspended</i>
Mar 81	0.19	2.8	0.10	263	3.0
Jun 81	0.25	0.4	0.17	282	1.0
Sep 81	0.02	-	-	224	6.0

Results of 2,4-D measurements are presented in Figure 1 for treatments in reconstituted water. It was determined that an average of 64.2 mg/g polymer was released within the first 24 hr after treatment. This initial "wash-out" was probably due to the portion of 2,4-D acid unreacted with the polymer in the formulation (Harris, personal communication). The release rates remained high during the next 3 days, with about 17 percent of the total 2,4-D applied being released by the end of this period. However, the release rate appeared to be stabilized at around 2.6 mg/g polymer/day throughout the remaining time of the experiment. The regression equation of release rates from Day 7 to Day 84 was  $Y = 96.25 + 2.61X$ ,  $R = 0.99$ . Based on this release rate, we estimated that the polymer formulation would be depleted of all 2,4-D in approximately 185 days.

Similar results were found with treatments of Poly (GMA) 2,4-D in natural water (Figure 2). After 1 week, the release rates stabilized at 2.3 mg/g polymer/day. The regression equation of release rates in natural water from Day 7 to Day 84 was  $Y = 97.50 + 2.29X$ ,  $R = 0.98$ .

Figure 3 compares cumulative release of the herbicide from Poly (GMA) 2,4-D into reconstituted and natural water over a period of 24 weeks. Similar release rates

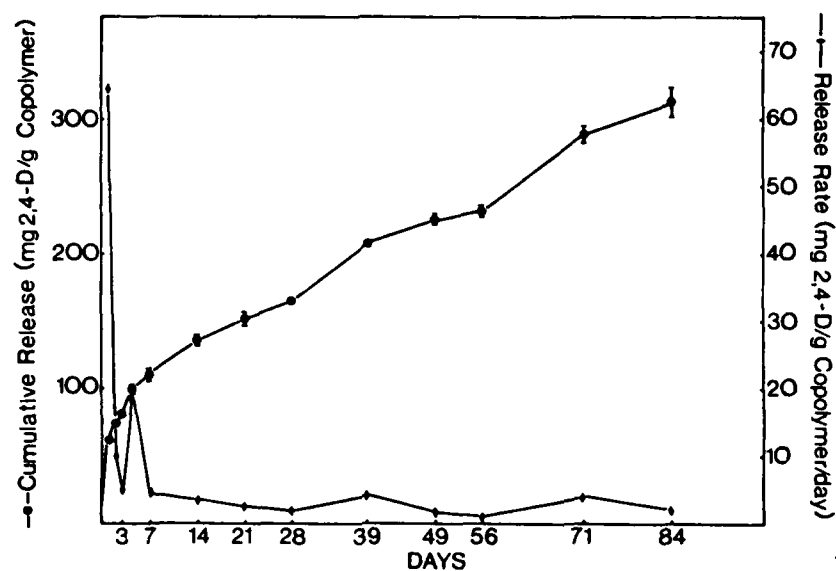


Figure 1. Release of 2,4-D from clay pellets of Poly (GMA) 2,4-D in static reconstituted water. Each point is the mean of four replicates  $\pm$  S.E.

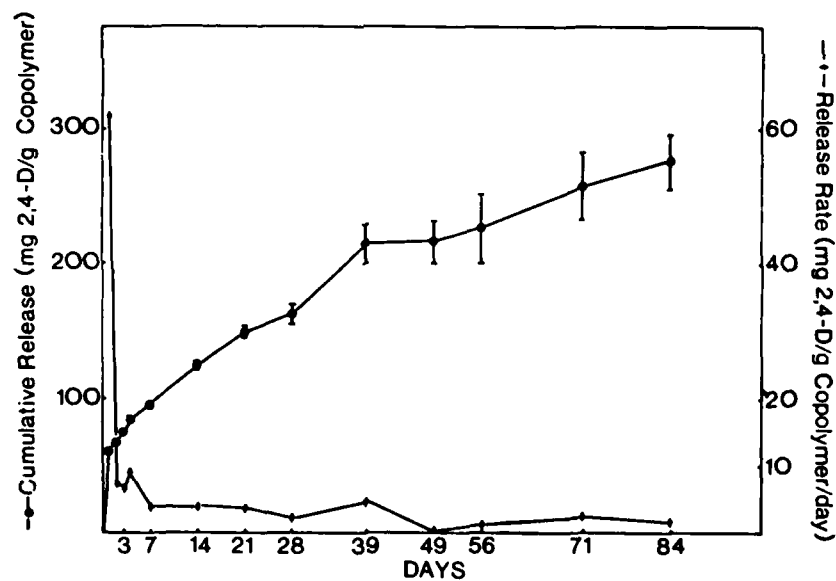


Figure 2. Release of 2,4-D from clay pellets of Poly (GMA) 2,4-D in static natural water. Each point is the mean of four replicates  $\pm$  S.E.

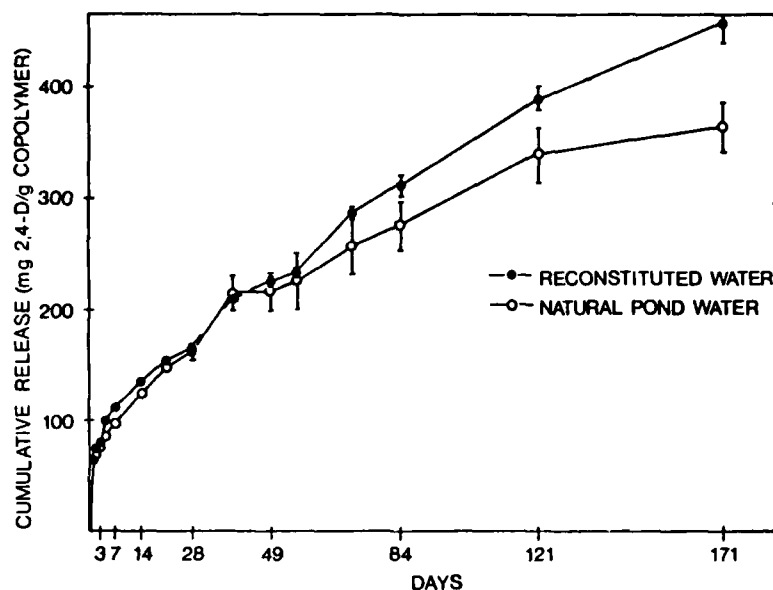


Figure 3. Cumulative release of 2,4-D from Poly (GMA) 2,4-D in reconstituted water and natural water

of 2,4-D were observed in treatments with reconstituted water and natural water during the first 8 weeks of the experiment. Release rates into reconstituted water remained unchanged in later sampling periods, indicating the constancy and reliability of release. In treatments with natural water, however, apparent release rates appeared to slow down significantly during the later part of the experiment. Higher microbial activity and algal growth were observed in treatments with natural pond water. These factors may have been partly responsible for faster disappearance of the released chemical in natural water.

#### Clay pellet Poly (GMA) 2,4-D in flowing natural water and efficacy against watermilfoil and Sago pondweed

Treatments of clay pellet formulation to maintain 0, 0.01, 0.02, 0.05, and 0.10 mg/l 2,4-D concentrations were made to 19 l of flowing water in glass, flow-through culture vessels with Eurasian watermilfoil and Sago pondweed. The plants were established in standard soil mix (70 percent sand and 30 percent organic peat) in 250-ml glass beakers. Three beakers each of watermilfoil and Sago pondweed were placed in the culture vessels. The plants were allowed to establish for 3 weeks before chemical treatment was applied. Treatments were replicated four times. Water flow was regulated to provide one complete exchange every 24 hr. Fifty-millilitre water samples were taken from each vessel at 1, 2, 3, 4, 7, 14, 21, 42, and 56 days after treatment. The samples were concentrated on SEP PAC® C<sub>18</sub> cartridges and analyzed for 2,4-D by high-pressure liquid chromatography.

Results of the analyses (Table 2) indicated again an initial wash-out of 2,4-D from the formulation, with an average release rate varying from 24.5 to 25.7 mg 2,4-D/g polymer for all treatment rates during the first 24 hr. These release rates were only about half of those observed in earlier static tests (Figure 2), presumably because of dilution by the flowing water and absorption and/or adsorption by plants and soil in the culture jars. Furthermore, the release rates appeared independent from the four treatment rates applied (Table 2).

**Table 2**  
**Measured Release of 2,4-D from Clay Pellets Poly (GMA) 2,4-D**  
**in Flowing Natural Water Conditions as Influenced**  
**by the Presence of Plants and Soil**

<i>2,4-D</i>		<i>mg/l Concentration of 2,4-D, Days After Treatment</i>								
<i>Treatment</i>		<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>7</i>	<i>14</i>	<i>28</i>	<i>42</i>	<i>56</i>
1.	0.01 mg/l									
	A	0.17	0.08	0.08	0.05	0.03	0.04	0.00	0.00	0.00
	B	0.26	0.14	0.08	0.06	0.05	0.01	0.00	0.00	0.00
	C	0.20	0.09	0.07	0.05	0.03	0.04	0.00	0.00	0.00
	D	0.31	0.14	0.08	0.06	0.03	0.01	0.00	0.00	0.00
	Average	0.23	0.11	0.08	0.06	0.04	0.03	0.00	0.00	0.00
2.	0.02 mg/l									
	A	0.42	0.26	0.16	0.10	0.08	0.10	0.00	0.00	0.00
	B	0.37	0.27	0.16	0.11	0.07	0.01	0.00	0.00	0.00
	C	0.37	0.25	0.17	0.12	0.04	0.01	0.00	0.00	0.00
	D	0.64	0.30	0.17	0.11	0.07	0.05	0.01	0.01	0.00
	Average	0.45	0.27	0.17	0.11	0.07	0.04	0.00	-	0.00
3.	0.05 mg/l									
	A	0.95	0.55	0.39	-	0.19	0.00	0.00	0.00	0.00
	B	1.09	0.61	0.37	0.27	0.20	0.08	0.02	BDL	BDL
	C	1.13	0.52	0.41	0.31	0.20	0.00	0.00	0.00	0.00
	D	0.95	0.58	-	0.32	0.11	0.10	0.13	BDL	BDL
	Average	1.03	0.57	0.39	0.30	0.18	0.05	0.04	-	-
4.	0.10 mg/l									
	A	2.16	1.48	0.81	0.65	0.35	0.02	0.04	0.00	0.00
	B	1.58	0.88	-	0.60	0.24	0.11	-	0.00	BDL
	C	2.18	1.19	0.73	0.56	0.36	-	0.02	BDL	0.00
	D	2.69	1.36	0.75	0.60	0.37	0.14	0.08	0.02	0.01
	Average	2.16	1.23	0.76	0.60	0.33	0.09	0.04	-	-
mg 2,4-D released per gram polymer (Means of 4 replicates).										
Treatment #1		25.2	12.6	8.5	6.0	3.6	3.3	0.0	0.0	0.0
Treatment #2		25.0	15.0	9.2	5.8	3.4	2.2	0.0	0.0	0.0
Treatment #3		24.5	13.2	9.3	7.2	4.2	1.1	1.0	-	-
Treatment #4		25.7	14.5	9.1	7.2	4.0	1.1	0.5	-	-

After 1 day, the average measured concentrations of 2,4-D in the flowing water were 0.23, 0.45, 1.03, and 2.16 mg/l for treatment rates calculated to maintain 0.01, 0.02, 0.05, and 0.10 mg/l, respectively. These 2,4-D concentrations gradually declined during the first week after treatment; however, they still remained at levels severalfold higher than those expected from the specified release rate of the formulation. The initial high levels of 2,4-D in the flowing water may have been responsible for the rapid injury response by watermilfoil plants. Heavy plant decay and algal growth were observed in the culture vessels 4 weeks after treatment in all treatment rates. These factors may act as sinks in taking up chemical, resulting in the disappearance of 2,4-D from the flowing water at later sampling periods (Table 2).

Figure 4 illustrates the influence of plants and soil on the measured herbicide levels in the flowing water. Treatments of Poly (GMA) 2,4-D were made with amounts calculated to maintain a constant 2,4-D concentration of 0.10 mg/l in the flowing water, based on the release rate of 2.3 mg 2,4-D/g polymer/day observed in static natural water (Figure 2). The actual 2,4-D concentrations measured after 24 hr were 1.6 and 1.8 mg/l, reflecting the initial wash-out of the formulation as observed earlier. Concentrations of the herbicide then decreased rapidly in treatments with plants and soil, and disappeared from the flowing water during the last 4 weeks of the experiment. In the absence of plants and soil, however, 2,4-D concentrations appeared to maintain around the expected level of 0.10 mg/l for a period of 4 weeks, after which a decline was observed.

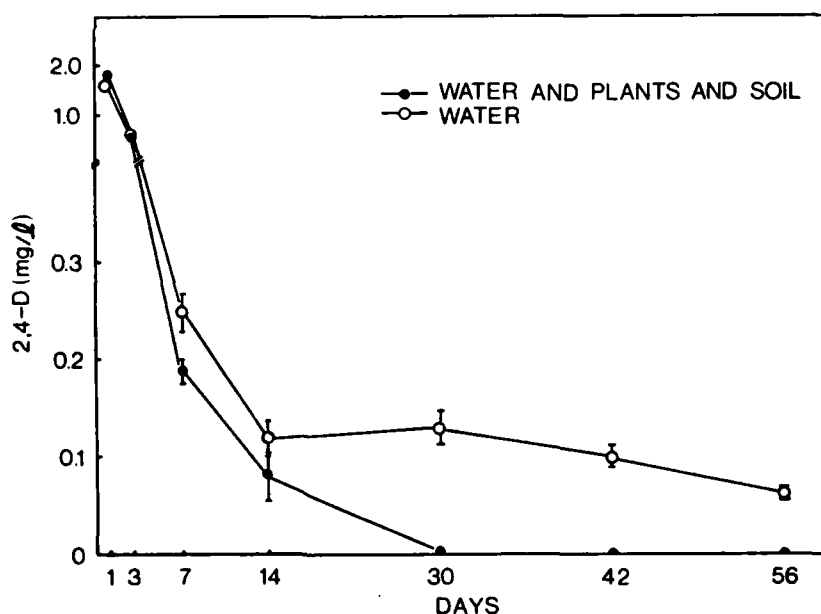


Figure 4. Release of 2,4-D from clay pellets Poly (GMA) 2,4-D in flowing natural water. Each point is the mean of four replicates  $\pm$  S.E.

The influence of various components in the experimental system that may act as sinks in taking up the released chemical was further investigated (Figure 5). The presence of soil in the culture vessels appeared to decrease the herbicide levels in water by approximately 40 percent when compared to the concentration in vessels without soil. Adding plants to the culture vessels further decreased the levels of 2,4-D in water, and the complete loss of the herbicide in the flowing water was again observed by 6 weeks posttreatment. These results suggested that higher release rates of chemical may be necessary for the formulation to effectively deliver enough herbicide not only to control plant growth, but also to compensate for any other components in the aquatic system acting as sinks in taking up the chemical.

The response of watermilfoil and pondweed to the 2,4-D formulation under flowing water conditions was evaluated closely during the first 2 weeks of the experiment. Elongation of main stems was observed in watermilfoil plants after 2 days in all treatment levels. However, further growth of the plants appeared completely suspended after this initial elongation phase. At treatment levels of 0.05 and 0.10 mg/l, a slight epinastic response of leaves at or near stem apices was observed 3 days after treatment, and was very pronounced after 1 week. At the end of 2 weeks, the upper portions of the main stems appeared darkened as though undergoing necrosis. Necrosis then spread down to near the base of the plants, and complete kill was obvious by 3 to 4 weeks after treatment at all four 2,4-D treatment levels. All control plants appeared healthy, erect, and of good color.

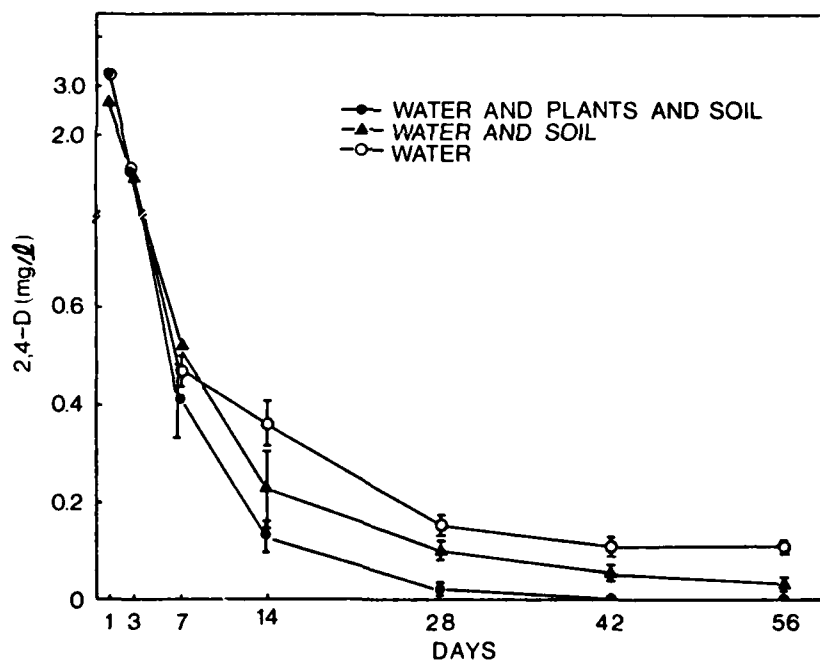


Figure 5. Influence of soil and plants on 2,4-D concentration in flowing natural water as released from clay pellets Poly (GMA) 2,4-D. Each point is the mean of four replicates  $\pm$  S.E.

After 5 weeks, a slight regrowth occurred in treatment levels in 0.01 and 0.02 mg/l in the form of a single branch arising from the nodes of damaged stems. However, the new branches eventually showed some injury response and none survived at the end of the experiment.

Sago pondweed appeared more tolerant to the treated levels of 2,4-D. All plants survived through the end of the experiment. No visual injury was observed on treated plants at 0.01 and 0.02 mg/l; however, several necrotic leaves and stems were apparent in higher treatment rates. The average injury after 8 weeks was 15 and 32 percent in plants treated at rates of 0.05 and 0.10 mg/l, respectively (Table 3). All plants were harvested 8 weeks after treatment, and stem lengths and plant weights were measured. The dry weight as well as growth in stem length were significantly lower in plants treated at 0.05- and 0.10-mg/l levels.

Table 3  
Effect of 2,4-D Release from Clay Formulation of Poly (GMA) 2,4-D  
on Watermilfoil and Sago Pondweed After 8 Weeks in Flowing Water

Treatments	Watermilfoil			Sago Pondweed		
	% Injury	Stem Length cm	Dry Weight per Plant g	% Injury	Stem Length* cm	Dry Weight per Plant* g
Control	0	42	1.57	0	62 <sup>a</sup>	2.19 <sup>a</sup>
0.01 ppm	100	0	0	0	67 <sup>a</sup>	1.79 <sup>a</sup>
0.02 ppm	100	0	0	0	63 <sup>a</sup>	1.88 <sup>a</sup>
Control	0	42	1.28	0	69 <sup>a</sup>	1.18 <sup>a</sup>
0.05 ppm	100	0	0	15	58 <sup>ab</sup>	0.87 <sup>b</sup>
0.10 ppm	100	0	0	32	48 <sup>b</sup>	0.69 <sup>b</sup>

\*Values within a growth parameter followed by the same raised letter do not differ significantly from each other.

#### Westvaco lignin formulation in static reconstituted and natural water

Release rates of 2,4-D from Westvaco lignin formulation in static reconstituted and natural water are presented in Figure 6. Linear regression analyses of the data indicated that release rates from day 1 to day 21 were approximately tenfold higher than the theoretical (designed) rate (1 to 2 mg 2,4-D/g pelletized formulation/day), with averages being 13.8 and 14.5 mg/g pellet/day for treatments in reconstituted and natural water, respectively. From day 21 to day 71, release rates slowed down significantly, being 2.1 mg/g pellet in both reconstituted and natural water. By day 71, approximately 86 percent of the total 2,4-D applied had been released. No further release was apparent from day 71 to day 84.

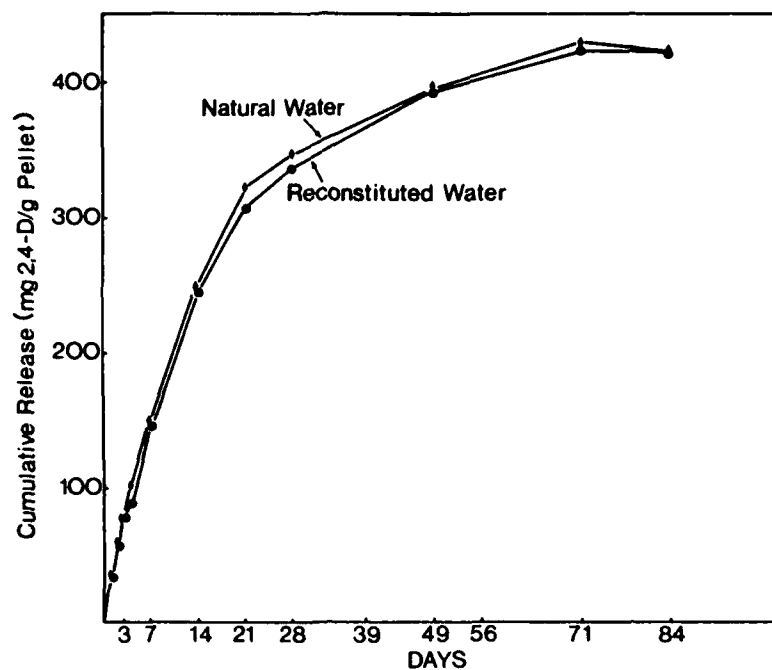


Figure 6. Cumulative release of 2,4-D from Westvaco 2,4-D/Kraft lignin in static reconstituted water and natural water

# CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

## Structural Studies of a Naturally Occurring Hydrilla Inhibitor

by  
Dean F. Martin\*

### INTRODUCTION

Various studies have noted certain lakes that do not support the growth of hydrilla (Martin, Doig, and Millard 1971; Martin, Victor, and Dooris 1976; Dooris and Martin 1980; Barko and Smart 1980; Barko 1981). The lakes that fail to have good growth of hydrilla do seem to favor good growth of other macrophytes (personal observations, Dooris and Martin, 1972-81), and thus suggestive evidence indicates some type of naturally occurring hydrilla inhibitor.

One such lake, Lake Starvation, Hillsborough County, Florida, is dark colored, and organic material from adjacent stands of bald-cypress (*Taxodium disticum*) comprises a significant fraction of the lake sediment; other lakes that appear to contain hydrilla inhibitors appear to have significant concentrations of organic material in the sediment that leads to the slow release of dissolved organic materials of presently unknown composition and structure.

Current efforts are directed toward purifying the fractions of water extracts of these sediments and characterizing the chemical nature of the active fractions.

Development of sufficient information would allow us to (a) monitor certain lakes less frequently for hydrilla infestation; (b) understand better the factors that control distribution of submersed aquatic plants; and (c) ultimately isolate, characterize, and produce, on a large scale, hydrilla-inhibiting material.

### EXPERIMENTAL

#### Isolation of lake sediment extracts

The details of the isolation of hydrilla-inhibiting extracts from Lake Starvation are given elsewhere (Martin and Dooris 1981), together with the details of the separation of components by ultrafiltration.

#### Fractionation of active components by high-performance liquid chromatography

The fraction that passed through a 10- $\mu$ m, but not a 2- $\mu$ m, filter (Amicon) was found to have maximum activity with respect to inhibition of growth of hydrilla in Hoaglands solution.

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\* Chemical and Environmental Management Services (CHEMS) Center, Department of Chemistry, University of South Florida, Tampa, Florida.

A C<sub>18</sub> reverse-phase chromatography cartridge was used for rapid sample preparation and to remove any problems caused by components tenaciously adhering to a packed high-performance liquid chromatography (HPLC) column. The cartridges were first wet with redistilled methanol, then washed with distilled water. Next, the sample was eluted through the cartridge, and the eluted sample was used for injection into the HPLC column.

Reverse-phase HPLC analysis was carried out using an Altex (Model 110A) chromatograph, with a solvent programmer attachment (Model 1601) and an ultraviolet (UV) detector (Model 153, 254 nm), and with an analytical scale column (Altex Ultrasorb, ODS 5  $\mu$  particle size). Appropriate fractions were collected during repeated sample injections and were assayed against *Chlamydomonas reinhardtii* using a Coulter electronic particle counter (Model ZB<sub>1</sub>) (Hess 1980).

### Mass spectrometry

Mass spectral analyses were performed at the Florida State University mass spectrometry laboratory using chemical ionization spectrometry in the range  $m/e = 90-650$ .<sup>\*</sup> Pertinent data are summarized in Table 1.

## RESULTS AND DISCUSSION

### Mass spectrometry

Fractions were tested for activity against *C. reinhardtii*, owing to the slight amount of active material available after separation by HPLC. The concentrations of individual fractions were slight inasmuch as a single 10- $\mu$ l injection corresponded to about 8  $\mu$ g. The fact remains, however, that an effect could be discerned (Martin 1982).

The maximum observed molecular weight was about 460 daltons (459 and 461 for two runs) (Table 1), and the data show a fair degree of consistency from one run to another for a given sample.

Possible molecular formulas can be calculated for each observed mass in the mass spectrum. With chemical ionization mass spectrometry, in contrast to electron-impact mass spectrometry, the molecular ion is not the most abundant. From the molecular formulas, it is often possible to determine the structure of the material under investigation, typically in comparison with known compounds. The length of time this requires varies with the complexity of the substance and the competence of the investigator.

The data in Table 1 are useful so far as they lead to a limited number of conclusions, including the following:

- a. There appears to be a general absence of significant contamination by dialkylphthalates, plasticizers that are ubiquitous contaminants. This is indicated by the absence of such fragments as C<sub>8</sub>H<sub>4</sub>O<sub>4</sub>, C<sub>10</sub>H<sub>8</sub>O<sub>6</sub>, C<sub>16</sub>H<sub>21</sub>O<sub>4</sub>, and C<sub>17</sub>H<sub>23</sub>O<sub>4</sub>, among others.

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<sup>\*</sup> $m/e$  = mass to charge ratio.

**Table 1**  
**Summary of High Resolution Mass Spectra of HPLC-Purified Sample of**  
**Hydrilla Inhibitor (Fraction 3)\* for Two Runs**

	<i>Observed Mass</i>	<i>Relative Intensity</i>	<i>Possible Formula</i>	<i>Observed Mass</i>	<i>Relative Intensity</i>	<i>Possible Formula</i>
1.	461.0168	1.8	C <sub>29</sub> H <sub>49</sub> O <sub>2</sub>	459.3483	1.1	C <sub>29</sub> H <sub>47</sub> O <sub>4</sub>
2.	399.3190	2.5	C <sub>27</sub> H <sub>43</sub> O <sub>2</sub>	-	-	-
3.	387.3473	2.7	C <sub>23</sub> H <sub>47</sub> O <sub>4</sub>	387.3280	5.1	C <sub>26</sub> H <sub>43</sub> O <sub>2</sub>
4.	386.3682	2.3	C <sub>24</sub> H <sub>50</sub> O <sub>3</sub> C <sub>23</sub> H <sub>49</sub> O <sub>3</sub> ** C <sub>23</sub> H <sub>48</sub> O <sub>3</sub> N	386.3342	14.1	C <sub>23</sub> H <sub>46</sub> O <sub>4</sub> C <sub>22</sub> H <sub>45</sub> O <sub>4</sub>
5.	386.3325	17.9	C <sub>23</sub> H <sub>46</sub> O <sub>4</sub>	-	-	-
6.	385.3315	51.2	C <sub>23</sub> H <sub>45</sub> O <sub>4</sub>	385.3312	38.1	C <sub>23</sub> H <sub>45</sub> O <sub>4</sub>
7.	-	-	-	372.3191	3.5	C <sub>22</sub> H <sub>44</sub> O <sub>4</sub>
8.	371.3004	8.8	C <sub>23</sub> H <sub>39</sub> O <sub>2</sub> C <sub>20</sub> H <sub>40</sub> O <sub>4</sub> N**	371.3172	9.2	C <sub>22</sub> H <sub>43</sub> O <sub>4</sub>
9.	151.0350	15.8	C <sub>7</sub> H <sub>6</sub> O <sub>3</sub> C <sub>8</sub> H <sub>7</sub> O <sub>3</sub>	151.0153	5.9	(C <sub>11</sub> H <sub>3</sub> O)
10.	149.0296	15.4	C <sub>12</sub> H <sub>3</sub> O	149.0433	2.6	(C <sub>12</sub> H <sub>5</sub> )
11.	134.0573	11.5	C <sub>5</sub> H <sub>10</sub> O <sub>4</sub>	134.0223	13.5	C <sub>7</sub> H <sub>4</sub> O <sub>2</sub> N C <sub>4</sub> H <sub>6</sub> O <sub>5</sub> C <sub>8</sub> H <sub>6</sub> O <sub>2</sub> N
12.	134.0455	9.0	C <sub>8</sub> H <sub>6</sub> O <sub>2</sub>	-	-	-
13.	133.0479	100.0	C <sub>5</sub> H <sub>9</sub> O <sub>4</sub>	133.0169	100	C <sub>4</sub> H <sub>5</sub> O <sub>5</sub> C <sub>7</sub> H <sub>3</sub> O <sub>2</sub> N
14.	119.0274	7.6	C <sub>4</sub> H <sub>7</sub> O <sub>4</sub> C <sub>7</sub> H <sub>6</sub> O C <sub>7</sub> H <sub>5</sub> ON	-	-	-
15.	-	-	-	118.8986	50.6	-
16.	-	-	-	112.8803	4.4	-
17.	-	-	-	99.8094	9.6	-
18.	97.1081	15.0	C <sub>7</sub> H <sub>13</sub>	-	-	-

\* Chemical ionization, 200°C, 8KV, 70 EV, CH<sub>4</sub> gas; see Figures 8 and 10 in Martin (1982) for additional description of Fraction 3.

\*\* C<sub>20</sub> means isotope ratio, i.e., 12C-13C.

- b. Some aromatic molecules are indicated by use of the ring-plus-double bonds formula; for C<sub>x</sub>H<sub>y</sub>N<sub>z</sub>O<sub>n</sub>, rings-plus-double bonds =  $x - 0.5y + 0.5z = 1$ . Thus, C<sub>29</sub>H<sub>47</sub>O<sub>4</sub> would have a total of rings-plus-double bonds of 8 (line 1, Table 1).
- c. Some fragments can be recognized by difference: CH (line 9 vs line 11); CH<sub>3</sub> (line 13 vs line 15); and C<sub>4</sub>H<sub>10</sub>O<sub>2</sub> (line 11 vs line 8), which is in agreement with an unsaturated alcohol.

### Other information

Other information comes from the infrared spectra which have strong absorbances, 3600-3630, 3100-3300, 1600-1650, and 1300-1080  $\text{cm}^{-1}$ , all of which are consistent with existence of aromatic, possible phenolic materials. Additional structural determinations are in progress.

### CONCLUSIONS

Two conclusions may be drawn from this study:

- a. A material that inhibits the growth of *Hydrilla verticillata* can be obtained from aqueous extracts of Lake Starvation sediment.
- b. Mass spectroscopy was useful in providing structural information that will help in efforts to identify the hydrilla inhibitors.

### ACKNOWLEDGEMENTS

The financial support of the U.S. Army Engineer Waterways Experiment Station (WES) is gratefully acknowledged as are the helpful comments of Dr. Howard Westerdahl and Mr. Ron Hoeppel of WES. The technical assistance of Mark J. Halvorson, Sandra L. Fisher, and Louise Worrell of the CHEMS Center is gratefully acknowledged.

### REFERENCES

- Barko, J. W. 1981. "Influence of Potassium Source (Sediment vs. Open Water) and Sediment Composition on the Growth and Nutrition of a Submersed Freshwater Macrophyte," *Aquatic Botany*, in press.
- Barko, J. W., and Smart, R. M. 1980. "Mobilization of Sediment Phosphorus by Submersed Freshwater Macrophytes," *Freshwater Biology*, Vol 10, p 229.
- Dooris, P. M., and Martin, D. F. 1980. "Growth Inhibition of *Hydrilla verticillata* by Selected Lake Sediment Extracts," *Water Research Bulletin*, Vol 16, pp 112-117.
- Hess, F. D. 1980. "A *Chlamydomonas* Algal Bioassay for Detecting Growth Inhibitor Substances," *Journal of Weed Science*, Vol 28, pp 515-520.
- Martin, D. F. 1982. "A Study of a Naturally Occurring Hydrilla Inhibitor, Phase I," Final Report, APCRP, in press.
- Martin, D. F., Doig, M. T., III, and Millard, D. K. 1971. "Potential Control of Florida *Elodea* by Nutrient-Control Agents," *Hyacinth Control Journal*, Vol 9, pp 36-39.
- Martin, D. F., and Dooris, P.M. 1981. "Study of a Naturally Occurring Hydrilla Inhibitor," *Proceedings, 15th Annual Meeting Aquatic Plant Control Research Planning and Operations Review, 17-20 November 1980, Savannah, Georgia*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 283-287.
- Martin, D. F., Victor, D., and Dooris, P. M. 1976. "Effects of Artificially-Introduced Ground Water on the Chemical and Biochemical Characteristics of Six Hillsborough County (Florida) Lakes," *Water Research*, Vol 10, pp 65-59.

# CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

## Development of Polymeric Controlled-Release Herbicide Systems

by  
Frank W. Harris\* and M. A. Talukder\*

### INTRODUCTION

The development of controlled-release herbicides has been one of the major objectives of this laboratory for the past several years. There are many distinct advantages to a controlled-release herbicide formulation. For example, it minimizes the presence of free herbicide in the environment because it releases only the amount needed to control the target organism, and it greatly reduces application costs since less frequent applications are needed.

One type of controlled-release formulation that offers considerable promise has the active agent chemically bound to a polymer backbone. Two different synthetic routes have been employed in the preparation of polymers that contain pesticides as pendent substituents. In the first, pesticides have been allowed to react with a prepolymers' functional groups.<sup>12-14</sup> In the second, pesticides are converted to polymerizable derivatives, which are subsequently polymerized to afford the macromolecular combination. The second route has been the major approach taken in this laboratory.<sup>1-11</sup> For example, several herbicide monomers, e.g., 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate (AOE 2,4-D) and 2-methacryloyloxyethyl 2,4-dichlorophenoxyacetate (MOE 2,4-D), have been synthesized and subsequently homopolymerized. These polymers, however, did not undergo hydrolysis under mild conditions. To enhance the hydrolysis process, hydrophilic groups were then introduced along the polymers' backbone. This was accomplished by the copolymerization of the herbicidal monomers with different hydrophilic comonomers, such as methacrylic acid (MA) and 2-hydroxyethyl methacrylate (HEMA). These copolymers did slowly undergo hydrolysis.<sup>3, 11</sup>

The major objective of this research was the synthesis and polymerization of a herbicidal monomer containing its own hydrophilic group. In particular, 2-hydroxy-3-methacryloyloxypropyl 2,4-dichlorophenoxy acetate (HMOP 2,4-D) was to be synthesized by the reaction of glycidyl methacrylate (GMA) with 2,4-dichlorophenoxyacetic acid (2,4-D). The monomer, which contains a free hydroxyl group, was to be homopolymerized and also copolymerized with HEMA and glyceryl methacrylate (HGMA).

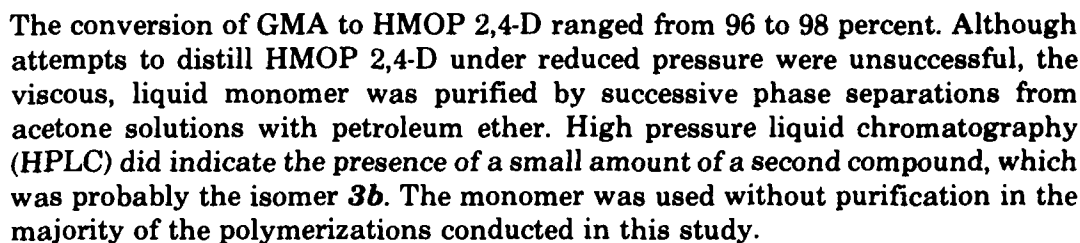
The second objective of this research was to investigate an alternate route to the homopolymer of HMOP 2,4-D. Thus, GMA was to be polymerized and the resulting

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## RESULTS AND DISCUSSIONS

The monomer HMOP 2,4-D was prepared by the reaction of 2,4-D with GMA in the presence of a quarternary ammonium salt catalyst, i.e. tetramethylammonium chloride. After the reaction was allowed to proceed at 70° C for 3 hr, the percentage of unreacted epoxy groups in the GMA was determined by titration:\*


$$\text{CH}_2 = \underset{\text{I}}{\underset{|}{\text{C}}}^{\text{CH}_3} - \overset{\text{O}}{\parallel} \text{C} - \text{O} - \text{CH}_2 - \overset{\text{O}}{\text{CH}} - \text{CH}_2 \xrightarrow[\text{H}^+]{\text{H}_2\text{O}} \text{CH}_2 = \underset{\text{4}}{\underset{|}{\text{C}}}^{\text{CH}_3} - \overset{\text{O}}{\parallel} \text{C} - \text{O} - \text{CH}_2 - \underset{\text{OH}}{\underset{|}{\text{CH}}} - \text{CH}_2\text{OH}$$

The homopolymerization of HMOP 2,4-D was carried out in methyl ethyl ketone (MEK) at 70° C with azobisisobutyronitrile (AIBN) as the initiator. Two different

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concentrations of the monomer were used, i.e. 60 percent w/w (**1a**) and 16.7 percent w/w (**1b**). The white polymer, which was isolated by precipitation in petroleum ether, was purified by successive reprecipitation from acetone with petroleum ether followed by extraction with ethyl ether. The yields of the polymer ranged from 45 to 65 percent. The homopolymer is soluble in several organic solvents such as THF, DMF, and aliphatic ketones, but is insoluble in aliphatic hydrocarbons, ethyl ether, and water. The homopolymer obtained from the concentrated polymerization mixture (**1a**) has a Tg of 42° C, while the Tg of the polymer obtained from the more dilute polymerization mixture (**1b**) has a Tg of 46° C (Table 1). It is very likely that

Table 1  
HMOP 2,4-D Homopolymers

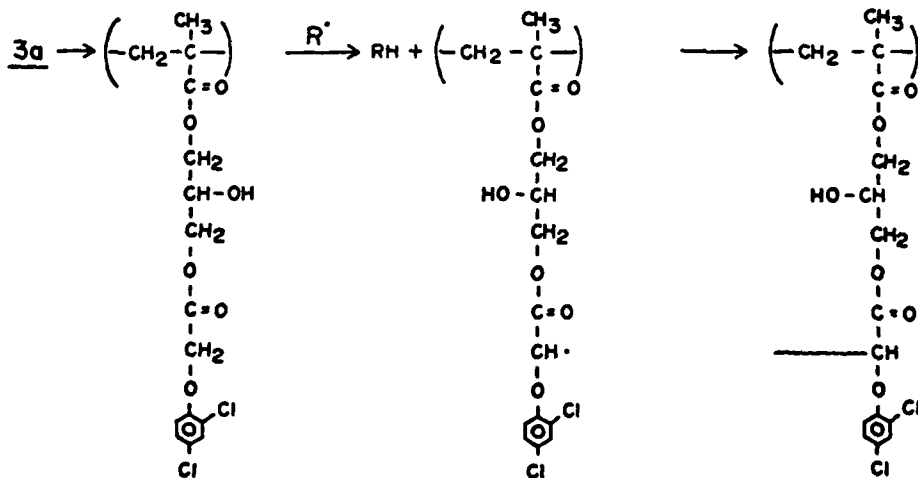
Polymer No.	Conversion percent	Tg* °C	η**
1a	65	42	0.21
1b	60	46	0.18
5a†	85	60	0.21

\* Determined from differential scanning calorimeter data.

\*\* Inherent viscosity (0.50 g/dl in DMF at 30°C).

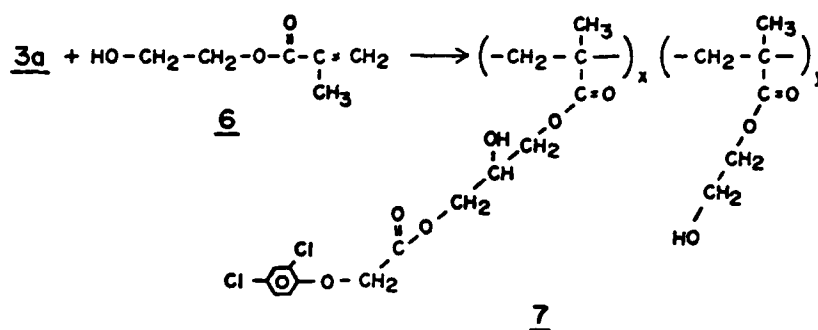
† Reaction of Poly (GMA) with 2,4-D of ratios 100:100.

some branching occurred in the former case, which would explain the lower Tg. Such branching could arise by free-radical abstractions of the hydrogens in pendent 2,4-D moieties, which would generate new polymerization sites along the backbone. Hydrogens located next to either linkage are known to be extremely susceptible to free-radical abstraction.



### Preparation of HMOP 2,4-D/HEMA Copolymers

Copolymerizations of HMOP 2,4-D and HEMA were carried out using molar feed ratios of 76:24 (**2a**), 66:34 (**2b<sub>1</sub>**), and 43:57 (**2c**). The copolymerizations were run in MEK at 70° C with AIBN as the initiator. The monomer mixtures were slowly added to the MEK solutions as the polymerizations proceeded. The final concentration of the monomers in MEK was 60 percent (w/w). The polymers, which were isolated by precipitation in petroleum ether, were reprecipitated from MEK with petroleum ether and then extracted overnight with ethyl ether. The yields of



purified material ranged from 35 to 55 percent. The copolymers displayed the same solubility behavior as the HMOP 2,4-D homopolymers. Their Tg's ranged from 48° to 52° C and increased as the percentage of HEMA in the copolymers increased (Table 2).

Table 2  
Reaction of Poly (GMA) with 2,4-D

Polymer No.	Reaction Feed Ratios	Conversion percent	Tg* °C	$\eta^{**}$
	Poly (GMA):2,4-D			
5a	100:100	85	60	0.21
5b	100:80	80	58	0.20
5c	100:60	70	50	0.20

\* Determined from differential scanning calorimeter data.

\*\* Inherent viscosity (0.50 g/dl in DMF at 30°C).

A copolymerization with a molar feed ratio of HMOP 2,4-D to HEMA of 66:34 (**2b<sub>2</sub>**) was also carried out with a total monomer concentration of 16.7 percent (w/w). The copolymer **2b<sub>2</sub>** obtained in this case has a Tg of 60° C, which is considerably higher than the Tg of a similar copolymer (**2b<sub>1</sub>**, Tg = 50° C) prepared in a more concentrated solution. This further substantiates the premise that the polymerization of HMOP 2,4-D in concentrated solutions results in branching.

### HMOP 2,4-D/HGMA copolymers

A series of copolymerizations of HMOP 2,4-D and HGMA was carried out in MEK with two different concentrations of the reactants, i.e. 60 percent w/w (**3a-c**) and 16.7 percent w/w (**4a-c**). The molar feed ratios of HMOP 2,4-D to HGMA used were 80:20, 64:36, and 51:49. The polymerization procedure and reaction workup were identical to those described for the HMOP 2,4-D/HEMA copolymers. The yields of the copolymers ranged from 22 to 50 percent (Table 3).

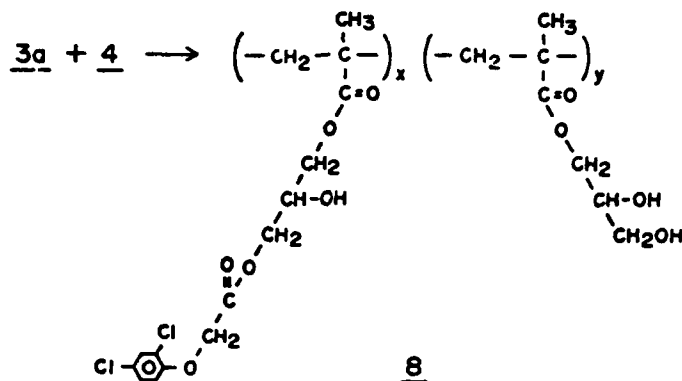


Table 3  
HMOP 2,4-D/HEMA Copolymers

Polymer No.	Initial Feed Ratios	Conversion percent	T <sub>g</sub> <sup>*</sup> °C	η <sup>**</sup>
	HMOP 2,4-D:HEMA			
2a	76:24	55	48	0.17
2b <sub>1</sub>	66:34	45	50	0.18
2b <sub>2</sub>	60:40	35	60	0.17
2c	43:57	35	52	0.19

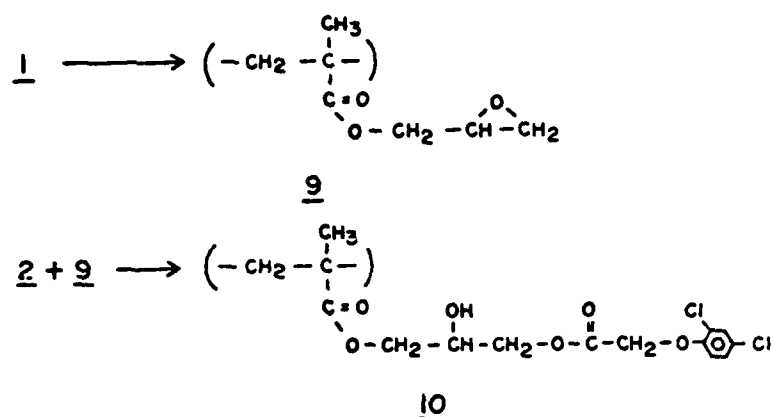
\* Determined from differential scanning calorimeter data.

\*\* Inherent viscosity (0.50 g/dl in DMF at 30°C).

The HMOP 2,4-D/HGMA copolymers are soluble and insoluble in the same solvents as the HMOP 2,4-D/HEMA copolymers. However, the T<sub>g</sub>'s of these copolymers are all higher, ranging between 50° and 55° C for **3a-c** and between 56° and 65° C for **4a-c**. Again, the copolymers prepared in more dilute solutions have the highest T<sub>g</sub>'s (Table 3).

### Homopolymerization of GMA

As mentioned, a secondary objective of this research was to investigate an alternate route to the homopolymer of HMOP 2,4-D. Thus, GMA was polymerized



and the resulting homopolymer treated with 2,4-D. The polymerization was carried out in MEK as described for the previous copolymers. The polymer was treated with three different levels of 2,4-D so as to afford products containing varying amounts of herbicide. The molar ratios of Poly (GMA) to 2,4-D used were 100:100 (**5a**), 100:80 (**5b**), and 100:60 (**5c**). In all three cases, the yields of product ranged from 70 to 85 percent. The polymers' Tg's ranged from 50° to 60° C and decreased as the percentage of epoxy group in the homopolymers increased (Table 4).

Table 4  
HMOP 2,4-D/HGMA Copolymers

Polymer No.	Initial Feed Ratio	Conversion percent	Percent Cl	Tg* °C	$\eta^{**}$	Copolymer Composition
	HMOP 2,4-D:HGMA					Mole Ratios HMOP 2,4-D:HGMA†
3a	80:20	50	15.35	50	0.46	62:38
3b	64:36	37	14.36	52	0.48	55:45
3c	51:49	26	16.38	55	0.49	69:31
4a	80:20	45	12.85	56	0.40	46:54
4b	64:36	33	11:88	60	0.41	41:59
4c	51:49	22	11.73	65	0.41	40:60

\*Determined from differential scanning calorimeter data.

\*\* Inherent viscosity (0.50 g/dl in DMF at 30°C).

†Determined from chlorine analysis.

### Hydrolysis studies

Three 0.5-g samples of each polymer were immersed in reconstituted hard water with a pH of 8.0. The solutions were stored at ambient temperature and slightly agitated. Their 2,4-D content was determined periodically by spectrophotometric analysis. The hydrolysis data of all the homopolymers and copolymers are summarized in Tables 5-9.

As shown in Table 5, the HMOP 2,4-D homopolymers initially released a small amount of 2,4-D and then essentially stopped releasing. The initial burst may have

**Table 5**  
**Hydrolysis Data for HMOP 2,4-D Homopolymers**

<i>Homopolymer 1a</i>			<i>Homopolymer 1b</i>			<i>Homopolymer 5a</i>		
<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>
2	2.42	0.39	1	2.3	0.38	3	2.0	0.33
7	6.66	1.09	7	13.08	2.15	5	12.0	2.0
12	16.57	2.7	12	18.3	3.0	11	19.5	3.2
24	23.6	3.8	18	23.58	3.87	28	20.0	3.3
50	32.15	5.3	33	30.65	5.05	32	21.0	3.5
170	44.8	7.3	58	30.65	5.05	55	23.0	3.8
						125	29.0	4.8

\* Average amount of 2,4-D released from three 0.5-g replicates in designated number of days.

been due to the release of an unreacted monomer that was trapped in the polymer matrix. The Poly (GMA) 2,4-D adducts behaved similarly (Table 6). Decreasing the amount of 2,4-D contained in the adduct had no effect on the release pattern. Evidently, the free epoxy groups in such polymers do not impart enough hydrophilicity to the system to affect immediate hydrolysis. It is possible that all these systems are releasing extremely slowly and will eventually undergo autoaccelerating hydrolyses.

The HMOP 2,4-D/HEMA copolymers also released a small initial burst of 2,4-D. Except in the case of copolymer 2c, the release rate decreased dramatically after approximately 50 days (Table 7). The former copolymer, which was prepared from a monomer feed containing 57 mole percent HEMA, released 2,4-D very slowly but at a considerably faster rate than the other HEMA copolymers. A copolymer obtained from a dilute polymerization mixture (2b<sub>2</sub>) showed a larger initial burst of 2,4-D than a similar copolymer obtained from a concentrated polymerization

**Table 6**  
**Hydrolysis Data for Poly (GMA) 2,4-D Adducts**

<i>Homopolymer 5a</i>			<i>Homopolymer 5b</i>			<i>Homopolymer 5c</i>		
<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>
3	2.0	0.33	3	2.1	0.36	3	2.0	0.40
5	12.0	2.0	5	7.0	1.3	5	3.6	0.73
8	17.0	2.8	8	9.0	1.6	8	4.6	0.94
11	19.5	3.2	11	10.5	1.9	11	6.0	1.2
28	20.0	3.3	28	14.0	2.5	28	11.0	2.2
32	21.0	3.5	32	15.0	2.5	32	12.4	2.5
55	23.0	3.8	55	16.0	2.8	55	14.0	3.0
125	29.0	4.8	125	22.5	4.0	125	21.0	4.3

\* Average amount of 2,4-D released from three 0.5-g replicates in designated number of days.

Table 7  
Hydrolysis Data for HMOP 2,4-D/HEMA Copolymers

<i>Copolymer 2a</i>			<i>Copolymer 2b<sub>1</sub></i>		
<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>
2	2.3	0.4	2	2.0	0.41
7	6.5	1.2	7	6.0	1.2
12	13.6	2.5	12	13.5	2.8
17	15.4	2.8	17	16.5	3.4
24	16.0	3.0	24	18.0	3.7
50	23.0	4.2	50	30.0	6.17
170	33.0	6.2	170	41.0	8.43

<i>Copolymer 2b<sub>2</sub></i>			<i>Copolymer 2c</i>		
<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>
1	2.5	0.51	2	2.1	0.5
7	25.23	5.19	7	7.7	1.8
14	29.0	5.96	12	20.5	4.8
29	41.0	8.43	17	22.0	5.2
55	42.0	8.74	24	24.0	5.6
			50	28.0	6.6
			170	51.6	12.6

\* Average amount of 2,4-D released from three 0.5-g replicates in designated number of days.

mixture (2b<sub>1</sub>). However, the release rate of this copolymer also decreased dramatically after the initial burst of herbicide.

The HMOP 2,4-D/HGMA copolymers obtained from concentrated polymerization mixtures (3a-c) released relatively large amounts of 2,4-D in the first 40 days following their immersion in hard water (Table 8). As with the HEMA copolymers, their release rates fell precipitously after their initial burst. The release rates of the HMOP 2,4-D/HGMA copolymers obtained from dilute polymerization mixtures (4a-c), however, only decreased slightly over a 96-day period (Table 9). The release rates of the three polymers under study were all approximately equal to a milligram of 2,4-D per gram of copolymer per day. This is not too surprising since chlorine analysis indicated that the compositions of all the copolymers were nearly identical (Table 4).

## CONCLUSIONS

The polymerization of concentrated solutions of HMOP 2,4-D results in branched polymers. Homopolymers of HMOP 2,4-D or polymers prepared from the reaction of Poly (GMA) with 2,4-D are not hydrophilic enough to undergo significant

**Table 8**  
**Hydrolysis Data for HMOP 2,4-D/HGMA Copolymers**  
**Obtained from Concentrated Polymerization Mixture**

<i>Copolymer 3a</i>			<i>Copolymer 3b</i>			<i>Copolymer 3c</i>		
<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>
3	10.0	1.8	3	9.8	1.9	3	8.0	1.88
8	73.0	13.9	8	36.0	7.5	8	26.0	6.1
20	109.0	19.9	20	42.0	9.0	20	40.0	9.38
35	141.0	25.8	35	56.0	11.5	35	55.0	12.9
43	156.0	29.0	43	74.0	15.0	43	60.0	14.1
130	163.0	30.0	130	77.0	15.8	130	72.0	16.9
250	163.0	30.0	250	77.0	15.8	250	72.0	16.9

\* Average amount of 2,4-D released from three 0.5-g replicates in designated number of days.

**Table 9**  
**Hydrolysis Data for HMOP 2,4-D/HGMA Copolymers**  
**Obtained from Dilute Polymerization Mixture**

<i>Copolymer 4a</i>			<i>Copolymer 4b</i>			<i>Copolymer 4c</i>		
<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>	<i>Days</i>	<i>Mg 2,4-D per g Polymer*</i>	<i>Percent 2,4-D Released</i>
1	5.37	1.34	1	5.0	1.35	1	5.6	1.53
5	13.0	3.25	5	10.0	2.7	5	12.0	3.29
10	21.0	5.25	10	18.0	4.86	10	22.0	6.04
25	33.0	8.25	25	41.0	11.08	25	42.0	11.5
34	39.0	9.75	34	45.6	13.25	34	46.0	14.0
49	57.0	14.25	49	58.0	15.67	49	63.0	17.85
64	80.0	20.0	64	75.0	19.72	64	82.0	22.52
96	106.0	26.5	96	100.0	27.03	96	104.0	28.57

\* Average amount of 2,4-D released from three 0.5-g replicates in designated number of days.

hydrolysis when immersed in hard water for 4 months. Copolymers of HMOP 2,4-D and HEMA containing as high as 57 mole percent HEMA also release 2,4-D very slowly under mild conditions. Linear copolymers of HMOP 2,4-D and HGMA, however, release 2,4-D at desirable rates, i.e. 1 mg per g of copolymer per day, for at least 3 months.

## REFERENCES

1. Post L.K., M.S. Thesis, Wright State University, Dayton, Ohio, 1974.
2. Aulabaugh, A.E., M.S. Thesis, Wright State University, Dayton, Ohio, 1977.
3. Thompson, J.W., M.S. Thesis, Wright State University, Dayton, Ohio, 1978.
4. Arah, C.O., M.S. Thesis, Wright State University, Dayton, Ohio, 1979.

5. Harris, F.W., et al., in "Controlled Release Polymeric Formulations," Paul, D.R., and Harris, F.W., eds., ACS Symposium Series, No. 33, Washington, D.C., 1976, p 222.
6. Harris, F.W., et al., in "Controlled Release Pesticides," Scher, A.B., ed., ACS Symposium Series, No. 53, Washington, D.C., 1977, p 102.
7. Harris, F.W., and Post, L.K., in "Proceedings, 1974 International Controlled Release Pesticide Symposium," Candarelli, N.F., ed., The University of Akron, Ohio, 1974.
8. Harris, F.W., and Post, L.K., *Am. Chem. Soc., Polym. Div., Preprints*, Vol 16, No. 2, 1975, p 622.
9. Harris, F.W., and Post, L.K., *J. Polym. Sci., Polymer Letters Ed.*, Vol 13, 1975, p 225.
10. Feld, W.A., Post, L.K., and Harris, F.W., in "Proceedings, 1975 International Controlled Release Pesticide Symposium," Harris, F.W., ed., Wright State University, Dayton, Ohio, 1975, p 113.
11. Whitlock, M.W., M.S. Thesis, Wright State University, Dayton, Ohio, 1980.
12. Jakubka, H.D., and Busch, E., *Z. Chem.*, Vol 13, No. 3, 1973, p 105.
13. Akagane, K., and Allan, G.G., *Shikizai Kyokaishi*, Vol 46, 1973, p 437.
14. Akagane, K., and Allan, G.G., *Shikizai Kyokaishi*, Vol 45, 1972, p 69.
15. Refojo, M.F., "Glyceryl Methacrylate Hydrogels," *J. Appl. Polym. Sci.*, Vol 9, 1965, p 3161.

# CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

## Evaluation of Controlled-Release 2,4-D Formulations In Lake Seminole, Georgia

by

Ronald E. Hoeppel\* and Howard E. Westerdahl\*

### INTRODUCTION

The evaluation of controlled-release (CR) herbicide formulations is a high-priority item of the Chemical Control Technology Development Project at WES. Although CR formulations may cost more to produce, effective costs for seasonal control, including application and labor, should be less than for conventional herbicide treatments. Also, CR formulations will impede elevated herbicide concentrations in the water column that could impact nontarget organisms. The delayed target aquatic plant regrowth following CR herbicide treatment could also allow for accentuated repopulation of the water body by more desirable aquatic plants. Even though the technology is presently available for developing good CR products for aquatic use, the potential market for the products is small, thus providing little stimulation for development and marketing by the private manufacturers. As a general rule, CR products developed for terrestrial use are of little value in aquatic environments. If the Corps is interested in aquatic plant control, it must be willing to help in product development and testing. This is the purpose of this phase of the WES aquatic plant control program.

The studies were conducted in the Spring Creek arm of Lake Seminole, Georgia, during the spring and summer of 1981 (Figure 1) and were designed to evaluate the fate and effects of two CR 2,4-D herbicide formulations. Experimentation, funded in part by the CE Mobile District, specifically involved a long-term efficacy evaluation of two new CR formulations for the control of Eurasian watermilfoil (*Myriophyllum spicatum*) under field conditions. The formulations tested were: 2,4-D acid in Kraft lignin pellets (Westvaco, Inc., North Charleston, S.C.) and Poly (GMA) 2,4-D (acrylic copolymer) in clay pellets (Wright State University, Dayton, Ohio).

### APPROACH

The two CR formulations were pretested in the laboratory to determine long-term release rates. Both showed comparable constant release rates of 0.2 to 0.3 percent of the 2,4-D acid per day for a period of 4 to 6 months. Also, the Poly (GMA) 2,4-D formulation was evaluated by the USDA Aquatic Plant Management Laboratory

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\*U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

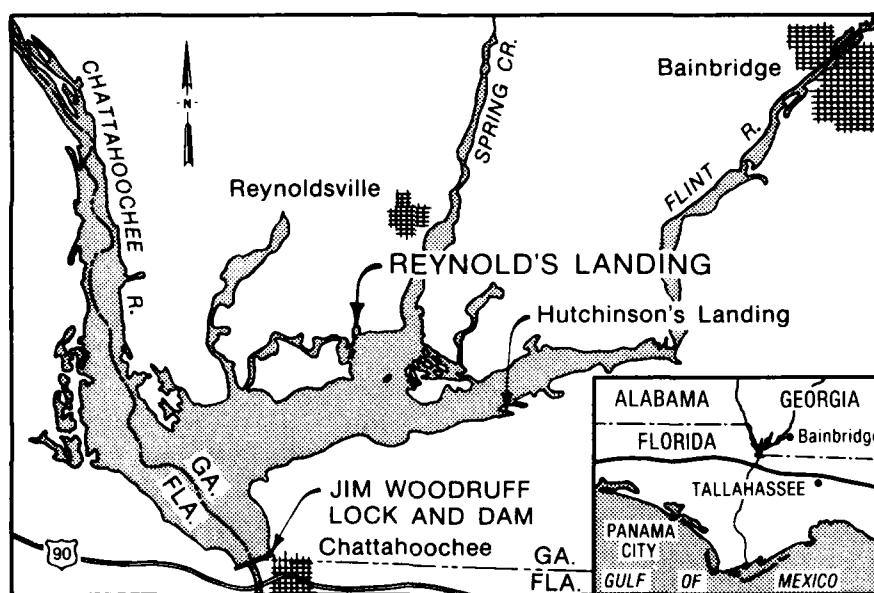


Figure 1. Location of the treatment plots in Lake Seminole, Georgia

(Fort Lauderdale, Fla.) for efficiency against watermilfoil in continuous-flow aquarium systems. A very similar CR formulation, MOE 2,4-D/GMA, was also previously evaluated (Steward 1981). These evaluations and a study by the Bureau of Reclamation with the MOE 2,4-D/GMA\* suggested that a sustained 2,4-D

\*Personal Communication, Fred Nibling, Bureau of Reclamation, Denver, Colo., Feb 1979.

concentration of 0.03 to 0.1 mg/l in the water column would control the growth of watermilfoil. This rate should be attainable near the sediment-water interface with an application of about 45 kg/ha 2,4-D acid equivalent (a.e) in these CR formulations.

Six, approximately 0.4-ha square plots were delineated in the Reynolds Landing embayment of Lake Seminole, Georgia (Figure 1). Each of four plots were treated on 28 April 1981 with two rates of 2,4-D acid in lignin pellets and two rates of Poly (GMA) 2,4-D clay pellets, respectively, applied by boat with a herbicide granule blower. Conventional 2,4-D BEE (Aqua-Kleen) was applied at the recommended rate to another plot, and a sixth plot received no herbicide treatment (reference). The plot size and treatment rates for each plot are given in Table 1. Qualitative changes in watermilfoil standing crop were monitored visually and with a survey fathometer equipped with a narrow angle transducer. Fathometer transects of the plots were made before treatment and at 1 month posttreatment. Water and sediment samples were collected from four designated quadrants within each plot. The water samples were obtained at about 0.3 m above the sediment. The sediment samples represented twofold to twentyfold compositing within each quadrant and were collected with a hand-held scoop with retractable lid to reduce loss of the surface sediment layer.

Table 1  
Description of Plots at Reynolds Landing

<i>Treatment</i>	<i>Application Rate</i>	<i>Plot Size</i>	<i>2,4-D (a.e.) Treatment Rate</i>
Reference	—	0.39 ha	—
Conventional 2,4-D (BEE) Aqua Kleen Granules (20% loading)	45.4 kg	0.38 ha	24 kg/ha
2,4-D acid in lignin pellets (50% loading)	22.7 kg	0.30 ha	38 kg/ha
2,4-D acid in lignin pellets (50% loading)	68.1 kg	0.38 ha	90 kg/ha
Poly (GMA) 2,4-D in clay pellets (10.4% loading)	163 kg	0.41 ha	41 kg/ha
Poly (GMA) 2,4-D in clay pellets (10.4% loading)	327 kg	0.34 ha	99 kg/ha

Water samples were analyzed for 2,4-D acid residues prior to treatment and 0.2, 2, 30, 70, and 112 days (4 months) following application. Herbicide residues were also determined in sediment samples collected prior to treatment and 1, 30, 49, 73, 112, and 147 days (5 months) posttreatment. The samples were placed in hexane-washed glass jars and stored at 4°C until analysis by gas chromatography

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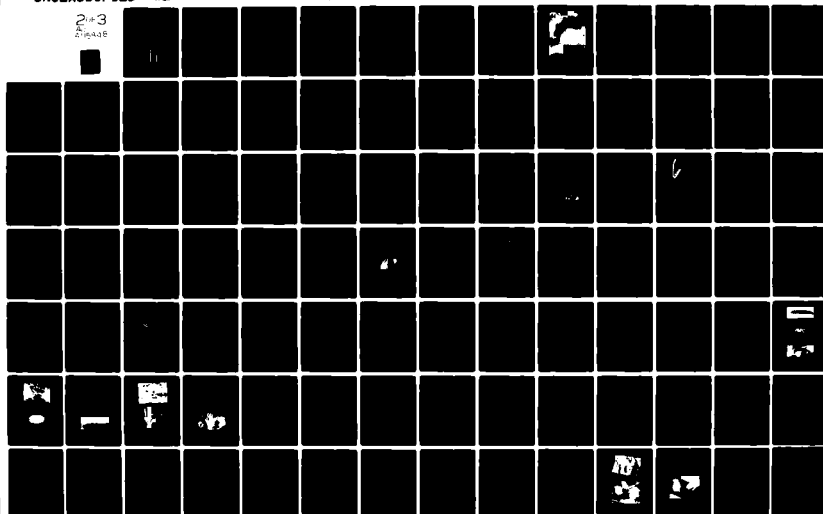
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according to standard procedures (American Public Health Association 1976).

A Hydrolab 8000 water quality monitor was used for determining water depth, temperature, conductivity, pH, and dissolved oxygen in each of the plot quadrants. Water quality monitoring was conducted simultaneously with the water sampling and at the same water depth.

## RESULTS AND DISCUSSION

### Water residues

The 2,4-D water residue data are given in Figure 2. The water residue values indicate that there was an appreciable dissolution of free 2,4-D acid from the Poly (GMA) 2,4-D CR formulation, comparable to the 24-kg/ha application rate of the conventional BEE 2,4-D herbicide. The 2,4-D pelletized lignin CR formulation showed a much lower initial 2,4-D release, with concentrations in these treatment plots being comparable to the reference plot (Figure 2). The high initial 2,4-D

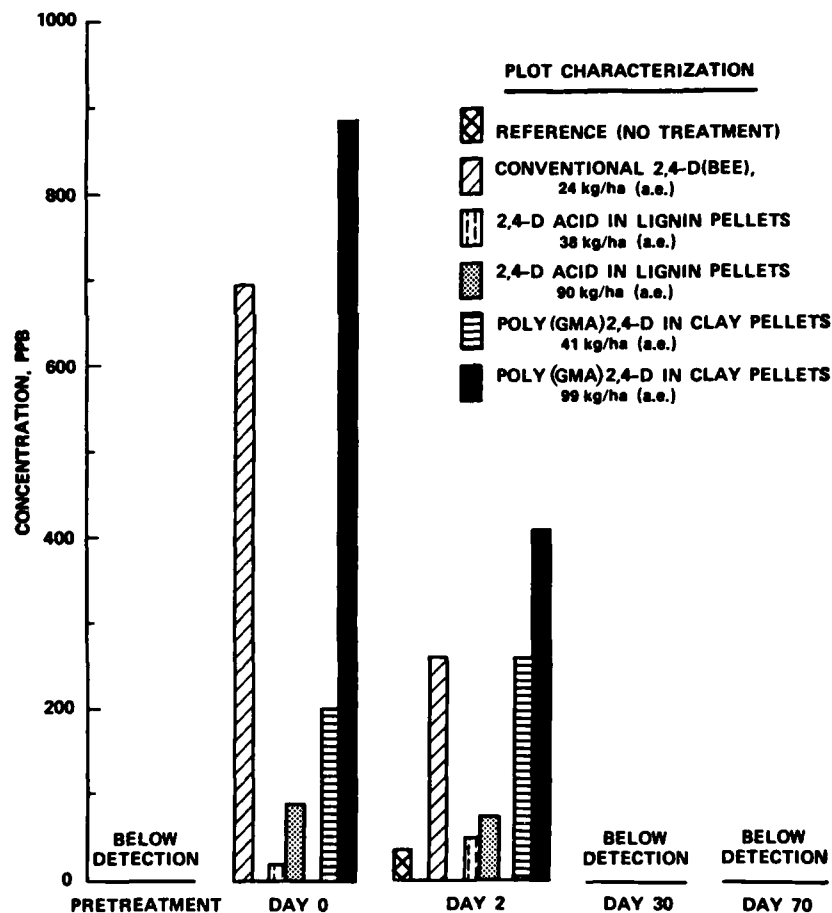


Figure 2. Concentrations of 2,4-D in bottom water samples from plots at Reynolds Landing, Lake Seminole, Georgia

releases from the Poly (GMA) and conventional 2,4-D formulations probably contributed to a 2,4-D concentration in the reference plot of greater than 0.035 mg/l after 2 days posttreatment. Water samples collected from all plots on and after 1 month posttreatment contained 2,4-D concentrations comparable to the pretreatment values of less than 0.005 mg/l. Although dye dissipation studies were not performed in the embayment, the rapid herbicide dissipation from the water and greater watermilfoil damage along shoreline areas strongly suggested that the almost totally enclosed treatment area had an appreciable positive flow of water into the main body of the lake. Thus, these studies are not comparable to those conducted in totally contained ponds.

### **Efficacy evaluations**

Both CR herbicide formulations failed to provide the desired long-term 2,4-D concentrations in the water column, perhaps aggravated by water movement through the treatment plots. However, observations and photographs made in the treatment plots during the study showed that some watermilfoil control was provided by both CR formulations. The apical meristems of nearly all of the watermilfoil growing within 0.2 to 0.5 m of the surface were killed throughout the entire embayment, with the initial signs of epinasty occurring on day 2. This phase of control was probably caused by the initial spike release of 2,4-D following application. However, 1 month after treatment very noticeable holes developed within the CR 2,4-D lignin treatment plots, with about a third of the standing watermilfoil completely decomposing and total plant biomass being reduced by half in the high rate plot. The high rate CR Poly (GMA) 2,4-D plot showed even greater reductions in the aquatic plant standing crop. After 1 month, only 5 percent of the watermilfoil remained with the remainder being totally decomposed; the remaining plants, surviving as small clumps, showed healthy meristems. The southern naiad (*Najas quadalupensis*) and most of the Illinois pondweed (*Potamogeton illinoensis*) also were dead or appeared moribund. The low rate treatment plot for the Poly (GMA) 2,4-D showed maximum control after 5 weeks with about half the plot barren of mainly watermilfoil; subsequent observations showed rapid regrowth of watermilfoil, which concealed the barren areas.

Between 8 and 10 weeks posttreatment, the high rate Poly (GMA) 2,4-D plot showed a further decrease of watermilfoil and pondweed but recolonization by southern naiad was rapid during this period. Chara was not affected by the treatments but recolonization by this alga was precluded by its slow growth. Observations continued for more than 5 months posttreatment (until 22 September), at which time the high rate Poly (GMA) 2,4-D plot remained covered with southern naiad and chara but showed no recolonization by watermilfoil or pondweed. The open areas in the high rate 2,4-D lignin plot also remained noticeable, but most of the watermilfoil standing crop in the treatment area once again reached the water surface, thus concealing many holes in the standing crop. Additional observations were not possible during the fall months because of exceptionally low water conditions in Lake Seminole.

## Sediment residues

The cause of the extended control of aquatic plants in the CR treatment plots, based on 2,4-D residue data in the water, was unresolved. Initial sediment data (day 1) also failed to show 2,4-D values significantly above background (pretreatment) levels, as shown in Table 2. Sediment analyses initially represented only a single (0.01 m<sup>2</sup> surface area) sample from each quadrant per plot; each set of four samples was composited for analysis. Sediment sampling on days 49, 73, and 112 represented a minimum of 16 samples per plot, compositing four per plot quadrant. The sampling on day 147 represented a minimum of 40 samples per plot (0.4 m<sup>2</sup> total surface area); 10 subsamples were collected from each quadrant. The samples were composited for two quadrants and duplicate samples were obtained from each composite to determine within-sample variability.

The greater compositing of sediment samples showed several moderate to high levels of 2,4-D, interspersed with some values at near background concentrations (Table 2). This variability was observed despite extensive mixing of wet and dry sieved sediment. A maximum 2,4-D acid value of 42 mg/kg was observed for the high rate CR 2,4-D lignin treatment plot on day 49. Day 73 and 112 sampling showed values of 19 and 3.4 mg/kg 2,4-D acid in sediment from the high rate CR

Table 2  
Average 2,4-D Acid Concentrations (mg/kg) in Sediment Samples  
from Reynolds Landing Plots

Treatment	Sample Collection Date					
	Pretreat*	Day 1*	Day 49**	Day 73**	Day 112**	Day 147†
Reference (no treatment)	0.95	—	—	—	—	0.45 (0.15-0.75)
2,4-D (BEE) (conventional)	0.2	0.25	—	—	—	—
2,4-D in lignin pellets (low rate)	0.8	0.2	—	—	—	—
2,4-D in lignin pellets (high rate)	0.7	1.0	13 (0.6-42)	0.2 (0.1-0.35)	0.35 (0.04-0.9)	0.45 (0.15-0.75)
Poly (GMA) 2,4-D in clay pellets (low rate)	0.65	1.2	—	—	—	—
Poly (GMA) 2,4-D in clay pellets (high rate)	0.25	0.15	2.2 (0.4-6.7)	5.2 (0.2-19)	1.15 (0.15-3.4)	0.8 (0.45-1.2)
Poly (GMA) 2,4-D clay pellets (collected from sediments)						1900††

\* Values represent four composited samples, one from each quadrant of each plot.

\*\* Values in parentheses represent ranges for four samples, one from each quadrant of each plot; each sample represents a composite of four subsamples.

† Values in parentheses represent ranges for four samples per plot; each sample represents a composite of 20 subsamples or a replicate within each of two composites.

†† Acid hydrolysis of clay pellet formulation (2 M H<sub>2</sub>SO<sub>4</sub>; sonication at 50° C for 1 hr).

Poly (GMA) 2,4-D treatment plot; background herbicide levels were observed in samples from the high rate CR 2,4-D lignin plot on these sampling dates (Table 2). All values for day 147 sediment samples from the CR treatment plots were comparable to background levels and composited sediment samples from the reference plot (Table 2).

Clay minerals in sediments and soils have been shown to repel or only weakly bind with 2,4-D at normal soil pH values. Only under acidic conditions, when 2,4-D acid is nondissociated, does binding with negatively charged colloids become significant (Weber, Perry, and Upchurch 1965; Grover and Smith 1974). However, 2,4-D and its breakdown products bind strongly with organic matter through salt linkages with divalent cations (Stevenson 1972), anion exchange forces (Weber, Perry, and Upchurch 1965), or covalent bond cross-coupling reactions with humus constituents (Bollag, Liu, and Minard 1980). Positively charged oxides of iron (i.e., goethite), which coat clay particles and clay-organic complexes, can also adsorb phenoxy herbicides (Watson, Posner, and Quirk 1973). Reversible desorption is also possible and is influenced by environmental factors such as pH (Stevenson 1972), temperature and time (Weber, Perry, and Upchurch 1965), and salt content and strength of the soil solution (Watson, Posner, and Quirk 1973).

The literature and experimental data suggest that the 2,4-D acid was slowly being released to the soft organic sediments into which the pelletized formulations sank. However, sediment binding may have prevented adequate movement of the herbicide through the sediment or into the water column. The resultant concentration gradient in the sediment immediately surrounding each pellet would also tend to slow the release rate of the 2,4-D acid from the CR formulations. These CR formulations may have been releasing the herbicide at the requisite rate, based on laboratory and greenhouse data, but release to the water column was being prevented by the organic sediments and biological debris. The aquatic plant control observed in the field was most probably by means of plant root uptake of the 2,4-D from the sediments. Due to the slow diffusion of herbicide, herbicidal activity occurred primarily within the immediate vicinity of disseminated pellets. The large open areas or holes in the CR 2,4-D lignin treatment plots probably resulted from an uneven distribution of the pellets. Widespread control in the high rate CR Poly (GMA) 2,4-D treatment plot probably resulted from the application of large quantities of pellets per unit area; about five times the number of CR Poly (GMA) 2,4-D pellets was disseminated compared to the CR 2,4-D lignin pellets because of the lower loading of the former.

#### **Water quality effects**

Water quality monitoring showed that no serious changes in water quality resulted from the CR herbicide applications. The dissolved oxygen and pH levels showed small decreases during the course of the monitoring. The pH decreased from a pretreatment afternoon value of 8.8 to an average afternoon value of 6.55 at 30 days posttreatment. The pH values approached pretreatment levels 70 days after treatment, when aquatic plant biomass approached pretreatment conditions

in most of the embayment. Only three bottom water dissolved oxygen readings were below 5.0 mg/l. One was in the high rate 2,4-D lignin treatment plot at a depth of 1.1 m and the other two were in very shallow water (0.05 m) in the high rate Poly (GMA) 2,4-D treatment plot. The reduced dissolved oxygen in the bottom water was related to decomposition of aquatic plant debris at the sediment surface.

## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this study:

- a. The high rate Poly (GMA) 2,4-D CR formulation, at 99 kg/ha 2,4-D acid, controlled almost all growth of watermilfoil and Illinois pondweed within the plot boundaries for a period of over 5 months; southern naiad was controlled for about 1 month.
- b. The high rate 2,4-D lignin CR formulation, at 90 kg/ha 2,4-D acid, controlled about 35 to 40 percent of the watermilfoil growth for a period of about 2 months; barren areas in the standing crop were noticeable 5 months posttreatment.
- c. The better herbicidal control observed by the Poly (GMA) 2,4-D formulation may have resulted mainly from a fivefold greater application of pellets (by weight) at one fifth the herbicide loading for this CR product.
- d. Concentrations of 2,4-D in the water columns of all treatment plots remained at background levels throughout most of the monitoring period (after 2 days posttreatment). This was probably due mainly to the binding of 2,4-D with the organic sediments.
- e. Both CR formulations probably elicited the major herbicidal action via root uptake of 2,4-D from the sediments.
- f. Southern naiad and chara recolonized the treatment plots during the period of active control with the CR herbicide formulations.

The recommendations suggested by this study include the following:

- a. Future field studies should be conducted using a new or improved carrier system for the Poly (GMA) 2,4-D formulation, whereby greater release occurs within the sediments. A carrier which remains at but not in the sediments should also be tested for improved release to the water column.
- b. A lower 2,4-D loading of the carrier (e.g., 10 percent by weight) is recommended for the 2,4-D lignin CR formulation.
- c. Field and greenhouse studies should be conducted to evaluate the effects of different sediment substrates (e.g., clay, sand, and organic muck) on the release rates of the CR formulations.

## REFERENCES

- American Public Health Association. 1976. *Standard Methods for the Examination of Water and Wastewater*, 14th ed., Washington, D.C.

- Bollag, J.-M., Liu, S.-Y., and Minard, R. D. 1980. "Cross-Coupling of Phenolic Humus Constituents and 2,4-dichlorophenol," *Soil Science Society of America Journal*, Vol 44, No. 1, pp 52-56.
- Grover, R., and Smith, A. E. 1974. "Adsorption Studies with the Acid and Dimethylamine Forms of 2,4-D and Dicamba," *Canadian Journal of Soil Science*, Vol 54, pp 179-186.
- Stevenson, F. J. 1972. "Organic Matter Reactions Involving Herbicides in Soil," *Journal of Environmental Quality*. Vol 1, No. 4, pp 333-343.
- Steward, K. K. 1981. "Evaluating Chemicals for Aquatic Plant Control," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-20 November 1980, Savannah, Georgia*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 265-282.
- Watson, J. R., Posner, A. M., and Quirk, J. P. 1973. "Adsorption of the Herbicide 2,4-D on Goethite," *Journal of Soil Science*, Vol 24, No. 4, pp 503-511.
- Weber, J. B., Perry, P. W., and Upchurch, R. P. 1965. "The Influence of Temperature and Time on the Adsorption of Paraquat, Diquat, 2,4-D and Prometone by Clays, Charcoal, and an Anion-Exchange Resin," *Soil Science Society of America Proceedings*, Vol 29, pp 678-688.

## CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

### 2,4-D Residue Dissipation Studies to Support Expansion of the Federal Label

by

Howard E. Westerdahl\* and Ronald E. Hoeppel\*

Over the past several years the Corps of Engineers (CE), Bureau of Reclamation (BOR), and Union Carbide have sought expansion of the 2,4-D tolerances affecting *Myriophyllum spicatum* control. Specifically, this expansion was to include the use of 2,4-D in water bodies other than those within the Tennessee Valley Authority. An Experimental Use Permit application was prepared and submitted to the Environmental Protection Agency (EPA) outlining proposed field studies to determine the 2,4-D dissipation rate in three reservoirs (Banks Lake in Washington, Ft. Cobb Lake in Oklahoma, and Lake Seminole in Florida and Georgia) representing cold and warm water reservoirs with different water quality characteristics. The Experimental Use Permits were granted to each Federal Agency in 1979.

Each field study was initiated during the period June to August 1980: Lake Seminole—June; Banks Lake—July; and Ft. Cobb Reservoir—August. Additional toxicological tests involving channel catfish, bluegill, and *Daphnia magna* were scheduled to be completed in early spring or summer 1982 by the Columbia National Fisheries Research Laboratory in Columbia, Mo. Only a summary of progress and significant findings at the Lake Seminole site will be described herein because the data from the other two field studies are not complete at this time. The data from Banks Lake and Ft. Cobb Reservoir will be analyzed and described by the BOR in Denver, Colo. The CE report on Lake Seminole and the BOR report on Banks Lake and Ft. Cobb Reservoir will be submitted jointly to EPA.

#### METHODS AND MATERIALS

Four 22-ha plots were selected in the Spring Creek arm of Lake Seminole (Figure 1). Each plot was located approximately 0.8 km apart. A reference station was located approximately 1.2 km below Plot 4 in the direction of the dam. This site was in a constricted section of Spring Creek and within the original river channel. Plots 1 and 3 were treated with 2,4-D DMA at 36 and 18 kg a.e./ha, respectively; and Plots 2 and 4 were treated with 2,4-D BEE at 36 and 18 kg a.e./ha, respectively. Water samples from two stations within each plot and three stations 152 m outside of three sides of each plot were collected at two depths (0.3 m below the water surface and 0.3 m above the sediment, respectively).

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\*U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

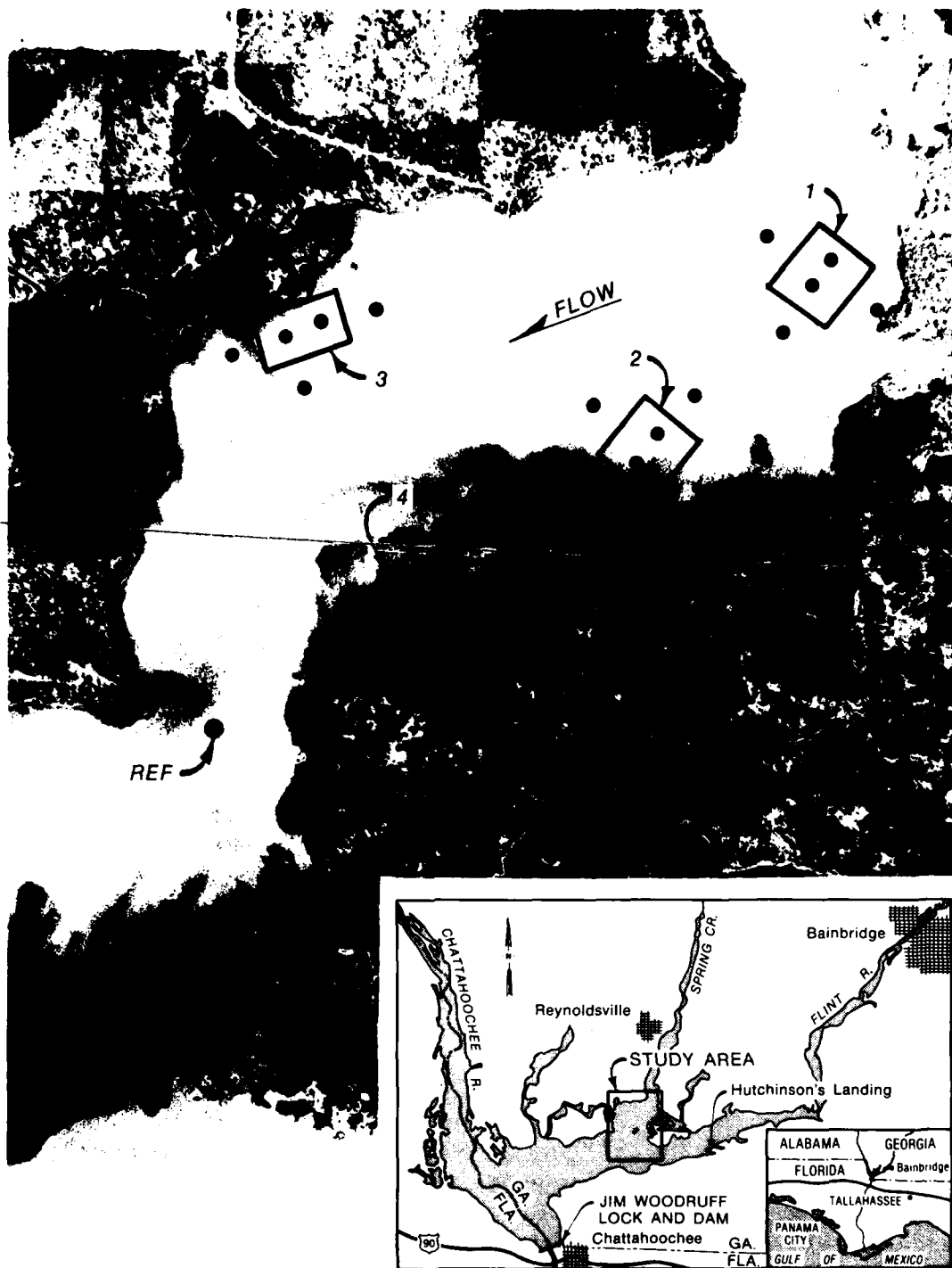


Figure 1. Area map and photograph of the Spring Creek study area showing the outline of each 22 ha plot; black dots represent sampling stations

These samples were analyzed for 2,4-D residues by the Tennessee Valley Authority in Chattanooga, Tenn. Results were compared with a middepth (3 m) sample from the reference station. Duplicate sediment samples were obtained from each of the two inside stations and analyzed for herbicide residues. The analytical procedures for determining 2,4-D BEE, 2,4-D DMA, 2,4-dichlorophenol, and dimethylnitrosamine concentrations in water and sediment were described in the Experimental Use Permit requests. These procedures use high pressure liquid chromatography using a Varian model 5000 equipped with a reverse phase C<sub>18</sub> column (MicroPAK MCH-10; Varian Associates, Palo Alto, Calif.). The 2,4-D levels in fish fillets were analyzed with a Ni<sup>63</sup> electron-capture detector. Five electroshocked fish, representing both edible and inedible species, were collected from within each plot on each sampling date. Only the edible flesh from each was analyzed for 2,4-D residues. Also, duplicate zooplankton samples were collected on each sampling date from one inside and one outside station of each plot, plus a vegetated reference station. These samples will be used to assess impacts of herbicide treatment on zooplankton diversity and abundance.

## RESULTS AND DISCUSSION

Water samples were collected at the five stations in and around each plot 1 week before treatment and 1, 4, 7, 13, and 28 days posttreatment. From Figure 2, the highest 2,4-D concentrations detected were 3.6 and 0.7 mg a.e./l, from 0.3 m below the water surface within the high rate 2,4-D DMA and 2,4-D BEE treatment plots, plots 1 and 2, respectively, on day 1. Also, the highest 2,4-D concentrations near the bottom of the water column from these two plots were approximately 2.0 and 0.4 mg a.e./l, respectively, on day 1. The highest 2,4-D concentrations found in the low rate 2,4-D DMA and 2,4-D BEE plots were 1.2 and 0.6 mg a.e./l, plots 3 and 4, respectively, at 0.3 m below the water surface on day 1. On the same day, the highest 2,4-D concentrations detected near the bottom of the water column were 0.8 and 0.5 mg a.e./l, respectively. Variations in water depth and flow between these two plots could have accounted for this. Water samples from stations outside contained approximately one tenth of the 2,4-D concentrations measured within each respective plot. By posttreatment day 7, the 2,4-D concentrations in water were below detection limits (<0.01 mg a.e./l) in all water samples, except the low rate 2,4-D BEE plot, which showed detectable herbicide on day 7. However, by posttreatment day 13, all water samples contained less than 0.01 mg a.e./l. Concentrations of 2,4-dichlorophenol (a degradation product of 2,4-D) remained below detection limits (<0.01 mg/l) in all plots prior to treatment and after treatment through day 68, respectively. Also, no measurable dimethylnitrosamine was ever found in the treated water throughout the study period. Water samples from the reference station contained nondetectable concentrations of 2,4-D and the aforementioned degradation products on all sampling dates.

Sediment samples were collected before treatment and on posttreatment days 4, 7, 13, 28, and 68. The 2,4-D acid concentrations in Plots 1 and 3 increased slightly above background on day 4 and decreased to background levels through day 68

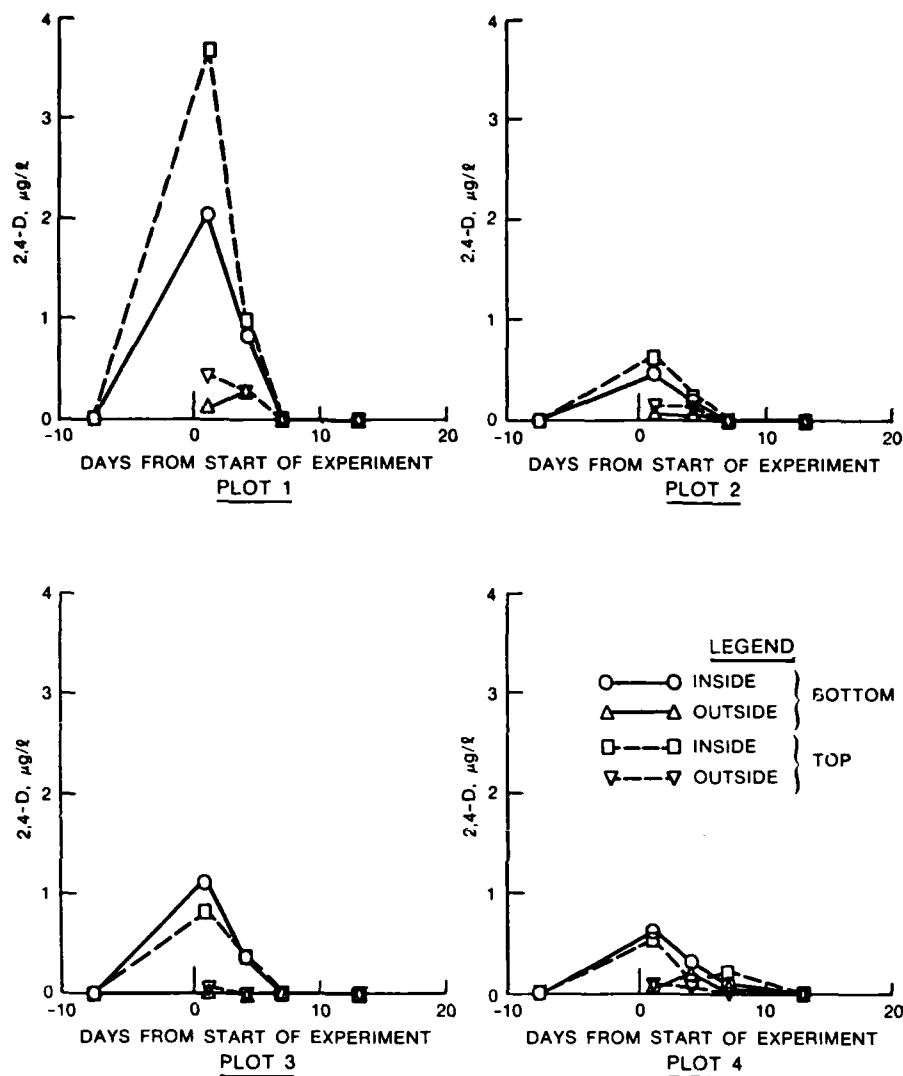


Figure 2. Residues of 2,4-D in top (0.3 m below the water surface) and bottom (0.3 m above the sediment) water samples from inside and outside sampling locations of each plot

(Figure 3). Two samples from Plot 1 on days 7 and 68 contained an unusually high 2,4-D acid concentration (approximately  $7 \mu\text{g/g}$ ) which skewed upward the 2,4-D acid concentration for these days (Figure 3). The 2,4-D acid concentration in sediment from Plots 2 and 4 increased to  $2.0$  and  $1.0 \mu\text{g/g}$ , respectively, by day 4 and decreased to background levels by day 28 in Plot 2 and day 7 in Plot 4. Figure 4 shows the sediment 2,4-D BEE concentrations measured in each plot. The results suggest little if any change in 2,4-D BEE concentrations when compared to the pretreatment levels. The 2,4-D BEE was apparently hydrolyzed to 2,4-D acid in the sediment or was bound to the sediment substrate.

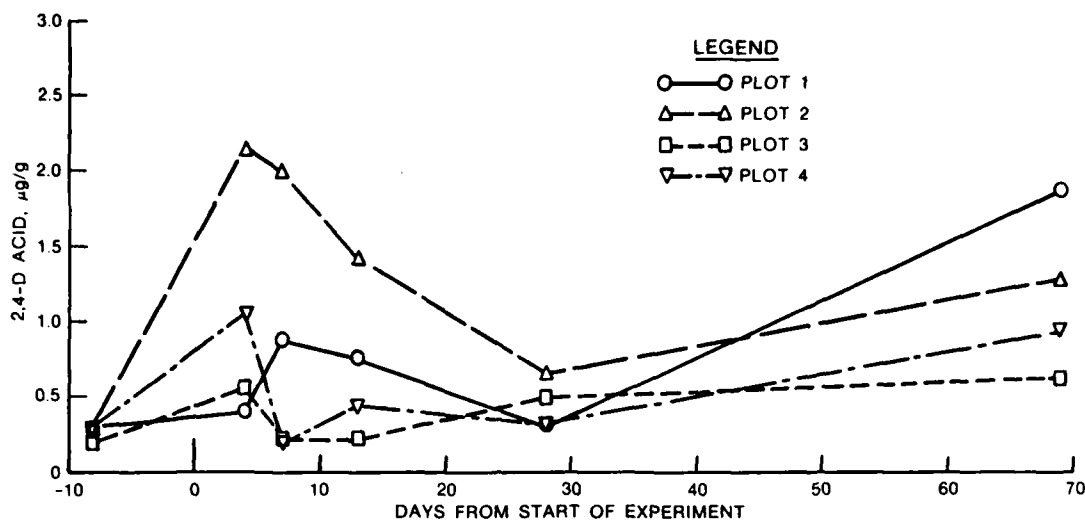


Figure 3. Residues of 2,4-D acid in sediment samples from each plot

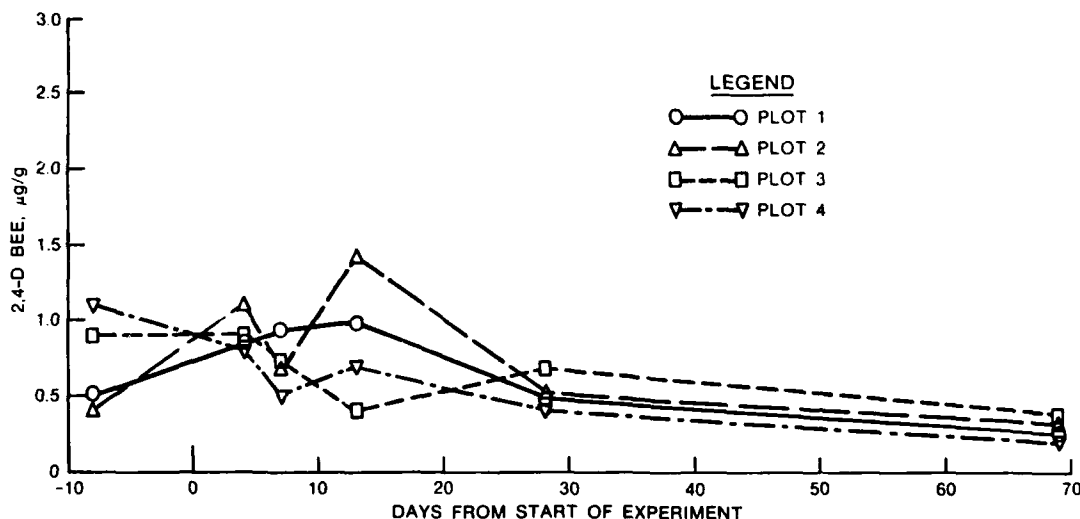


Figure 4. Residues of 2,4-D BEE in sediment samples from each plot

Natural fish populations were collected from within the treatment plots before treatment and on posttreatment days 1, 4, 7, 13, 28, and 69. None of the edible fish (e.g., bass, sunfish, and catfish) collected from within the plots treated with 2,4-D DMA contained detectable 2,4-D concentrations ( $>0.01 \mu\text{g a.e./g}$ ) in edible flesh (Figure 5). The 2,4-D residue in flesh of only one game fish collected from Plot 4 showed a slight increase in 2,4-D concentration, i.e.  $0.3 \mu\text{g a.e./g}$ , on day 4. Only gizzard shad (inedible species) obtained from the 2,4-D BEE plots through day 7 contained 2,4-D residues in edible flesh that exceeded existing EPA tolerances; maximum concentrations on days 1, 4, and 7 were  $3.8$ ,  $5.0$ , and  $2.8 \mu\text{g a.e./g}$ , respectively.

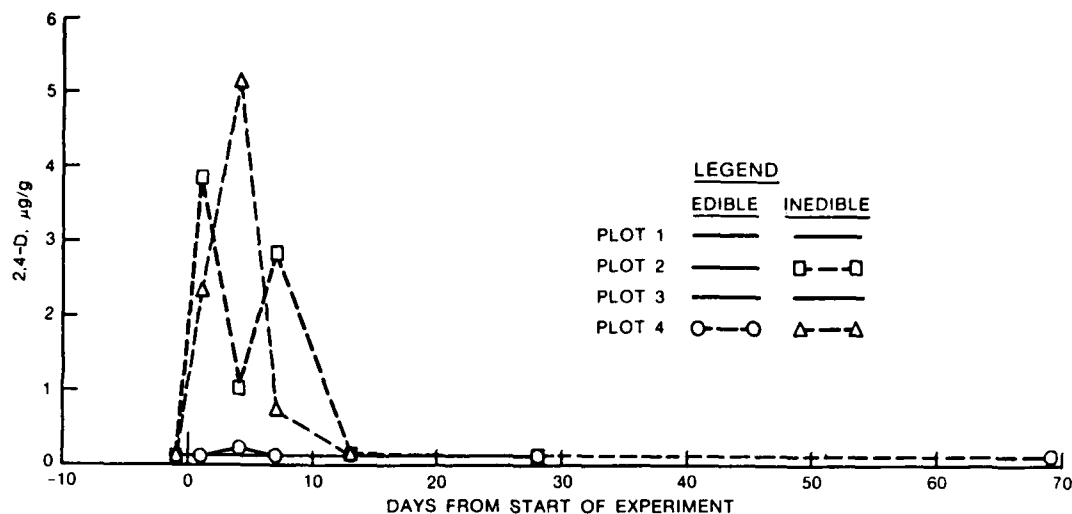


Figure 5. Residues of 2,4-D in fillets from edible and inedible fish collected by electroshocking throughout each plot

The 2,4-D concentrations in fish collected in all of the plots from day 13 through day 68 were at or below detection limits. The initially high 2,4-D levels in shad may be attributed to direct ingestion of disintegrated 2,4-D BEE clay pellets shortly after application.

Zooplankton samples were collected and preserved before treatment and on posttreatment days 1, 4, 7, 13, 28, and 69. These data will be analyzed by April 1982. Water quality characteristics, i.e., conductivity, pH, and dissolved oxygen, were not appreciably affected following herbicide treatment.

These results suggest that 2,4-D is not persistent in the water and sediment of open bodies of water, and does not accumulate in the edible flesh of fish. In June 1982, the results of this study will be compiled and submitted to the EPA in conjunction with the BOR's findings on Banks Lake and Ft. Cobb Reservoir, with a request for expansion of the 2,4-D tolerance and Federal registration. Also, additional toxicity tests with bluegill, channel catfish, and *Daphnia magna* will be conducted as requested by EPA and results will be submitted to the EPA as soon as possible.

#### ACKNOWLEDGEMENT

The assistance of Messrs. Howard Wilson and Tom Marshall, Department of Fish and Game, State of Georgia, in providing the equipment and assistance required to electroshock and capture fish for this study is greatly appreciated. In addition, the assistance of Mr. Angus Gholson, Resource Manager of Lake Seminole, and his staff, especially Mr. Holmes Walters, is also appreciated.

# THE GROWTH OF *MYRIOPHYLLUM SPICATUM* L. IN RELATION TO SELECTED CHARACTERISTICS OF SEDIMENT AND SOLUTION

by  
John W. Barko\*

## BACKGROUND

Considering the dual source of nutrient supply, sediment and open water, to rooted aquatic vegetation (Sculthorpe 1967; Denny 1972), it is not surprising that detailed nutritional investigations conducted in a variety of freshwater systems have failed to conclusively demonstrate a specific nutrient limitation of submersed macrophyte growth (Peltier and Welch 1970; Carpenter and Adams 1977; Patterson and Brown 1979; Peverly 1980). Even in oligotrophic systems possessing infertile sediments, submersed macrophytes are apparently able to maintain adequate tissue nutrient levels through seasonal conservation of biomass and nutrients (Moeller 1978; Sand-Jensen and Søndergaard 1979). In such systems, macrophyte productivity may be diminished, but the maintenance of appreciable macrophyte biomass is not necessarily precluded (Rich, Wetzel, and Thuy 1971). In many aquatic systems, nutrition may be less important than other environmental factors regulating broad variations in the growth and distribution of submersed macrophytes (Spence 1967; Davies and Brinson 1980; Barko and Smart 1981a).

In previous investigations conducted in this laboratory, sediments obtained from numerous mesotrophic-eutrophic systems in the United States have provided substantial variations in the growth of the submersed macrophytes *Hydrilla verticillata* Royle and *Myriophyllum spicatum* L. under identical conditions of light, temperature, and water chemistry (Barko and Smart 1980). These sediment-related variations in growth have not been attributable to specific nutritional deficiencies. In a recent investigation (Barko 1982), the growth of *Hydrilla* was significantly retarded on two highly organic sediments compared to growth on other less organic sediments. These results compared favorably with observations made in situ, and it was tentatively suggested that sediment organic matter might assert a regulating influence on the growth of this species.

Considering the several ecological similarities between *M. spicatum* and *Hydrilla* (Barko and Smart 1981a), it is of interest to assess the growth performance of the former on sediments promoting variations in the growth of the latter. In this connection, the growth of *M. spicatum* is examined here on a variety of sediments including those used previously in the related *Hydrilla* investigation.

The presently reported investigation consisted of three phases of experimentation: a main body of study (MBS) and two secondary studies. The MBS was

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\*U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

designed primarily to examine the effects of different sediments on the growth of *M. spicatum*, but was conducted in two ionically distinct solutions (Table 1). Both solutions have been used previously as macrophyte growth media in this laboratory, where some qualitative indications have suggested their differential abilities to support the growth of *M. spicatum*. Secondary studies were designed as extensions of the MBS to examine selected characteristics of sediment and solution on the growth of *M. spicatum*. Details concerning the general rationale underlying the conduct of these secondary studies are provided later in the text.

**Table 1**  
**Chemical Characterization of Experimental Solutions**  
(All values are expressed in milligrams  
per litre unless otherwise designated.)

<i>Constituent</i>	<i>Solution 1</i>	<i>Solution 2</i>
Ca	20.0	7.5
Mg	6.0	4.1
Na	5.0	9.0
K	4.3	2.3
CO <sub>3</sub> + HCO <sub>3</sub> *	30.0	14.7
SO <sub>4</sub>	44.1	16.6
Cl	1.3	21.2
N	4.0	0.0
P	0.0	0.0
Micronutrients**	Complete	Complete
<b>Determination</b>		
pH	7.4	7.2
Conductivity, $\mu\text{S} \cdot \text{cm}^{-1}$ (20°C)	180	140
Dissolved inorganic carbon (DIC)	5.5	2.5

\*Concentrations of CO<sub>3</sub> + HCO<sub>3</sub> were achieved by additions of CaCO<sub>3</sub> and NaHCO<sub>3</sub> to solutions 1 and 2, respectively.

\*\*All essential micronutrients were added as a 1:10 dilution of formulations specified in Bold's Basal Medium (Nichols and Bold 1965).

## METHODS AND MATERIALS

The MBS and one of the secondary studies were conducted in 1200-l fiberglass tanks housed in the greenhouse facility described in Barko and Smart (1981a). Plants in the greenhouse were exposed to natural diel variations in irradiance beneath 33 percent shade fabric, allowing maximum penetration of photosynthetically active

radiation (PAR) approximating  $1000 \mu\text{einstein's} \cdot \text{m}^2 \cdot \text{sec}^{-1}$ . The other secondary study was conducted in 20-l lucite columns housed in the controlled environment facility described in Barko and Smart (1980). Irradiance in this facility was provided during a 14-hr photoperiod at ca.  $350 \mu\text{einstein's} \cdot \text{m}^2 \cdot \text{sec}^{-1}$  (PAR). In all phases of experimentation, water temperatures were maintained at  $24^\circ \text{C}$ .

Six of the seven sediments upon which the growth of *M. spicatum* was examined in the MBS are characterized in Barko (1982). Lakes from which these sediments were obtained, their locations in the United States, and abbreviations designating single or multiple sites (in parentheses) are: Grassy Pond, south Georgia (GP); Kerr, eastern Oklahoma (Kerr-1 and 2); Seminole, northern Florida (Sem-1 and -2); and Starvation, central Florida (Starv). An additional sediment used in the MBS and in the secondary studies was obtained from Lake Washington, Washington State (Wash). Physical and chemical characteristics of Wash sediment were nearly identical to those reported in Barko and Smart (1981a) for sediment obtained from the same site 1 year previously. Another sediment possessing a fine-grained texture, which has been used for submersed macrophyte culture in this laboratory, was obtained locally from Openwood Lake in Vicksburg, Mississippi (Open), for use in one of the secondary studies.

Polyethylene 1-l sediment containers with a surface area of  $90 \text{ cm}^2$  were used in the greenhouse studies. The volume and surface area of lucite sediment containers used in the controlled environment facility approximated 3 l and  $100 \text{ cm}^2$ , respectively. Each sediment was thoroughly mixed before being placed into the sediment containers. Sediments were allowed an adequate period of time for settling, with necessary adjustments made in volume prior to planting.

In all phases of the investigation, *M. spicatum* was grown from apical tips (ca. 10 cm in length), removed from a uniform greenhouse culture initiated from plants obtained in north-central Florida. Within each phase of study, an equal number of apical tips (three to four) were allocated to each sediment container. These tips were planted to a sediment depth of ca. 5 cm, with the sediment surfaces then overlaid with ca. 2 cm of washed silica sand, thereby minimizing material exchanges between sediment and the overlying solution.

Solutions were formulated by additions of reagent grade chemicals to distilled or deionized water. In order to minimize interference from algae during the conduct of these studies, none of the solutions contained phosphorus (Table 1). Past experience and a growing body of supportive literature indicated the substantial ability of submersed macrophytes to satisfy phosphorus nutrition by mobilizing this element directly from sediments (Barko and Smart 1981b and literature cited therein). As in past investigations conducted in this laboratory, solution volumes were periodically replaced to maintain defined water chemistry conditions.

The main body of study was conducted over an 8-week period. Secondary studies were conducted over periods of 6 weeks each. Treatment-related differences in the growth of *M. spicatum* were determined from estimates of dry weight biomass accrual. Tissue nutrient concentrations were determined as in Barko (1982).

Statistical analyses of experimental data were performed using the Statistical Analysis System (Raleigh, N. C.). All comparisons of growth and nutrition in *M. spicatum* in relation to experimental treatments were based on a minimum of three replications. Statements of significance made in the text refer to the 5 percent level (or less) of statistical confidence.

## RESULTS AND DISCUSSION

### Main body of study

Overall variations in the growth of *M. spicatum* between solutions and among sediments demonstrated significant trends (Figure 1). On those sediments providing intermediate to maximum plant growth, biomass production was substantially greater in solution 1 than in solution 2. In contrast, the influence of solution on biomass production was apparently negated on Kerr-2, Starv, and Sem-2 sediments, which provided the poorest growth of *M. spicatum*. Sediment-related differences in the growth of this species followed similar patterns in both solutions, but were of unequal intensity (i.e., range in biomass production in solution 1 > range in solution 2).

The ratio of root-to-shoot biomass in *M. spicatum* was unaffected by solution, but varied over a nearly fivefold range (increasing with decreased biomass production) on the various sediments (Figure 1). Sediment had a much greater effect on the production of shoots than roots. Accordingly, root-to-shoot biomass ratios in Figure 1 primarily reflect differences in the growth of shoots.

High ratios of root-to-shoot biomass are characteristically associated with plants growing in infertile environments (Chapin 1980). Additionally, it has been suggested that stress factors not directly related to plant nutrition (such as salinity for instance) may influence these ratios (Barko and Smart 1979). In a variety of submersed freshwater macrophytes, root-to-shoot biomass ratios have been demonstrated to vary inversely with growth rate, being greater on sand than on mud (Denny 1972). Here, variations in this parameter among sediments are dramatic, but do not relate directly to sediment texture.

Although the poor growth of *M. Spicatum* on the extremely sandy Kerr-2 sediment (84 percent sand by dry weight) appears to be a texturally related phenomenon, perhaps involving nutrition, the equally poor growth of this species on Starv and Sem-2 sediments, both muds (one fine textured and one coarse textured), cannot be explained by considering texture alone. Texture also bears no relationship to the similarity in growth of *M. spicatum* on Kerr-1 (a fine-textured sediment) and on GP (an extremely sandy sediment).

In an initial attempt to account for major experimental variations in the growth of *M. spicatum*, tissue nutrient analyses were performed. Nitrogen (N) and phosphorus (P) concentrations were determined (Figure 2) because of their overall physiological importance in plant growth as well as their differential inclusion or lack of inclusion in the two solutions used in this study (Table 1).

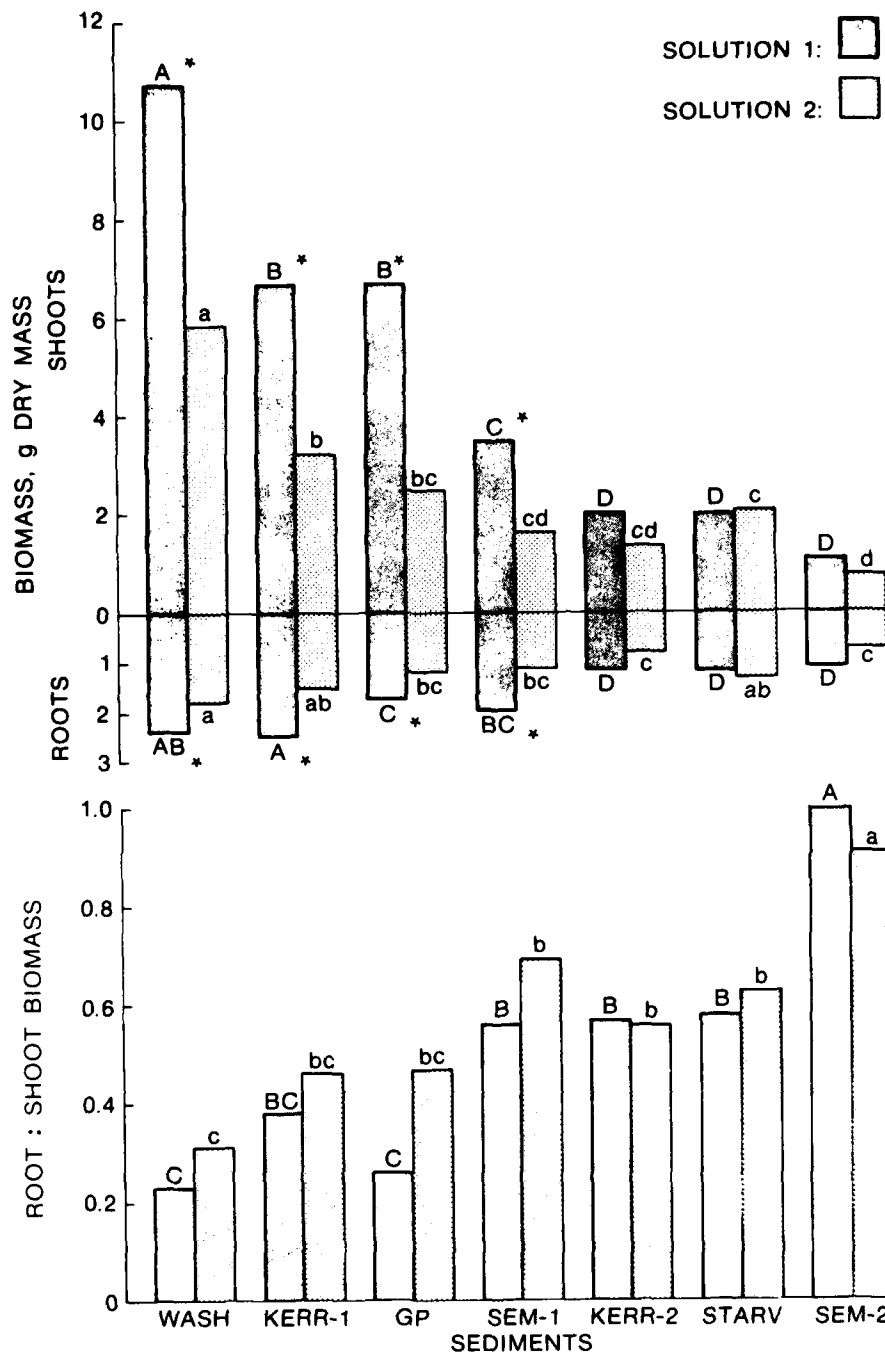


Figure 1. Total biomass production and root-to-shoot biomass ratios in *M. spicatum*. Asterisks indicate significant effects of solution on growth. Within each solution, biomass values and root-to-shoot biomass ratios sharing the same letter across sediments do not differ significantly from each other

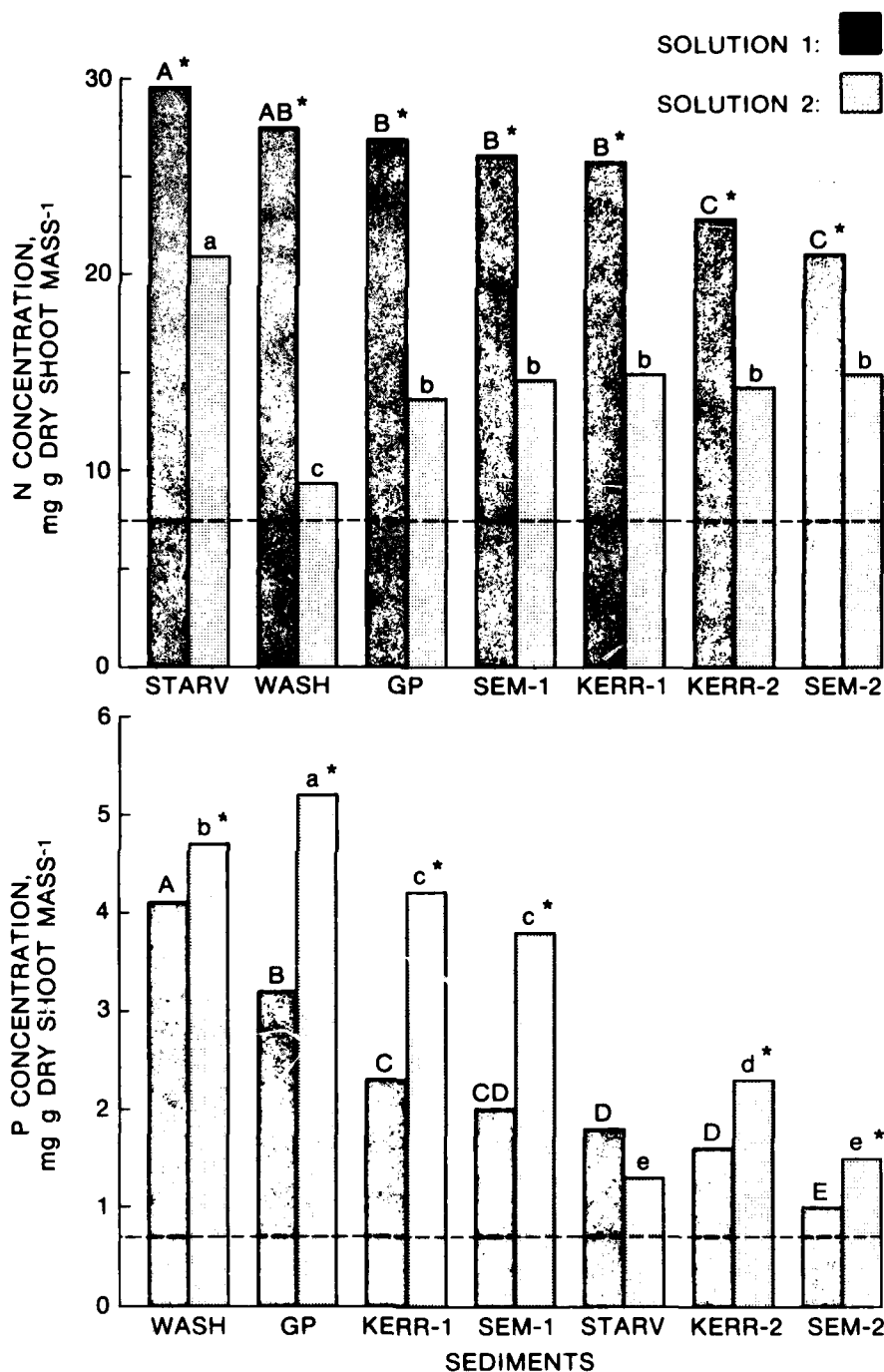


Figure 2. Nitrogen and phosphorus concentrations in shoots of *M. spicatum*. Broken horizontal lines indicate critical (i.e., growth-limiting) concentrations. Asterisks indicate significant effects of solution on nutrition. Within each solution, nutritional response variables sharing the same letter across sediments do not differ significantly from each other

Variations in shoot N and P concentrations between solutions generally exceeded variations in the same among sediments within either solution (Figure 2). The greater N concentrations in shoots from solution 1 compared to shoots from solution 2 apparently reflect the respective presence versus absence of N in these two solutions. In contrast, P (absent from both solutions) was generally more concentrated in shoots from solution 2 than in shoots from solution 1, suggesting dilution of P associated with the greater biomass production of *M. spicatum* in the latter solution.

Using the criteria (i.e., critical nutrient concentrations) established by Gerloff (1975) for *M. spicatum*, neither N nor P appears to have been "growth-limiting" in this study. From the shoot P data presented above, differences in growth between solutions clearly cannot be ascribed to P limitation. Phosphorus was mobilized to a lesser extent from sediments providing least biomass production in this study; yet this is interpreted here as a consequence, rather than a cause of reduced plant growth (as considered in Chapin 1980; Clarkson and Hanson 1980). Shoot nitrogen concentrations bear little relationship here to differences in the growth of *M. spicatum* among sediments. However, the notable correspondence apparent in the foregoing between N supplied in solution, respective shoot N concentrations, and plant growth raises the possibility that differential N supply could account for differences in the growth of this species between solutions.

In combination with the data and information presented above, additional data including major cations in shoots (not presented) suggest that sediment-related variations in the growth of *M. spicatum* cannot be associated with a specific nutrient limitation in this study. An identical conclusion was reached in the related investigation of *Hydrilla* growth on the same sediments (Barko 1982). Notably in that study, the ordering of sediments in relation to their macrophyte growth-promoting potentials was nearly identical to the ordering reported here with the two highly organic sediments, Starv (29 percent) and Sem-2 (56 percent), providing relatively poor production of total biomass. A secondary study involving organic matter additions to sediment was designed to experimentally examine the possible relationship between sediment organic matter composition and the growth of *M. spicatum*.

#### **Secondary study on sediment effects**

In a secondary study of sediment effects, organic matter, representative of various types of vegetation (both aquatic and terrestrial) was dried, ground in a Wiley Mill, and uniformly added to Wash sediment, thereby increasing the organic content from ca. 10 percent to ca. 20 percent on a dry mass basis. Solution 1 was provided as the aqueous growth medium during this study, which was conducted in the greenhouse.

The growth of *M. spicatum* on all of the amended sediments was significantly retarded in comparison with growth on the nonamended Wash sediment (Figure 3). Moreover, wide variations in the magnitude of apparent growth inhibition occurred with different organic matter additions. These results suggest that the

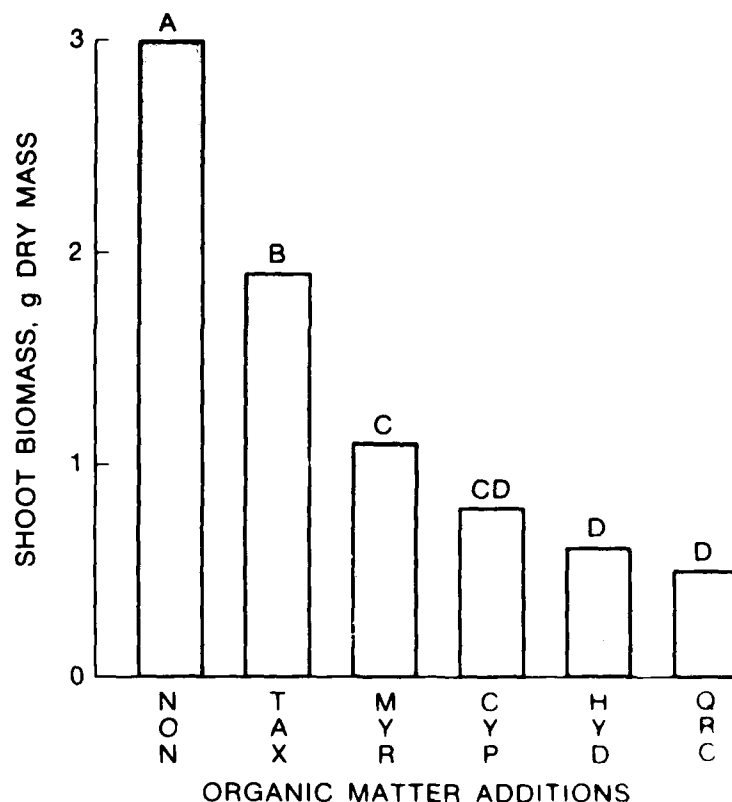


Figure 3. Shoot biomass production in *M. spicatum* on sediment amended by organic matter additions. Non = non-amended Lake Washington sediment. Amendments include additions of: Tax = sawmill debris of *Taxodium* spp.; Myr = shoots of *M. spicatum*; Cyp = tubers of *Cyperus esculentus* L.; Hyd = shoots of *H. verticillata*; Qrc = leaves of *Quercus* spp. Biomass values sharing the same letter do not differ among sediment treatments.

chemical composition of organic matter incorporated into sediments has an important influence on the relationship between sediment organic content per se and the growth of *M. spicatum*.

In deference to the positive relationship between the growth of submersed macrophytes and low-level variations in sediment organic matter noted in infertile oligotrophic systems (Sand-Jensen and Søndergaard 1979; Kiørboe 1980), high-level accumulations of organic matter in sediments of eutrophic systems may retard the growth of submersed macrophytes. Organic matter additions to inorganic coarse-textured sediments undoubtedly improve fertility directly by increasing nutrient supplies and indirectly by enhancing ionic exchange properties. However, in highly organic sediments, these beneficial effects may be overshadowed by low redox potentials, accumulations of organic acids, low pH, increased metal availability, and evolution of growth-inhibiting gases, among other considerations (Drew and Lynch 1980 and literature cited therein). Results of

this line of investigation are preliminary, but repeatable (Barko, unpublished), and do establish a relationship between organic loadings to sediments and the decreased growth of *M. spicatum*. Because of the possible significance of these results to macrophyte succession in lacustrine systems (Wetzel 1979), the influence of sediment organic matter composition on the growth of other macrophytes needs to be examined as well.

### Secondary study on solution effects

In order to more discriminantly examine the relationship between solution composition and differences in the growth of *M. spicatum*, noted in the MBS, a secondary study involving alterations in solution chemistry was conducted in the controlled environment facility. Major differences in the composition of solution 1 and 2 (Table 1) were independently negated by additions of single chemical compounds to solution 2, thereby achieving concentration parity with selected elements (Ca, inorganic C, and N) in solution 1. Openwood sediment was provided as a rooting substratum during this study.

Consistent with results obtained on maximum growth-promoting sediments in the MBS, the growth of *M. spicatum* on Open sediment was substantially greater in solution 1 than in solution 2; solution chemistry had no influence on root-to-shoot biomass ratios (Figure 4). The addition of N to solution 2 did not affect the growth of this species, either on Open sediment (Figure 4) or on Wash sediment (Barko, unpublished data). Thus, the different capacities of solution 1 and 2 to support the growth of *M. spicatum* in these studies cannot be attributed to differences in solution N. Independent additions of  $\text{KHCO}_3$ ,  $\text{NaHCO}_3$ ,  $\text{CaCl}_2$ , and  $\text{CaSO}_4$  to solution 2 increased the growth of *M. spicatum* to similar extents and approximately halved the growth margin between solutions 1 and 2. With the addition of  $\text{CaCO}_3$  to solution 2, the growth of *M. spicatum* in terms of both its morphological development (Barko, personal observations) and production of biomass was essentially indistinguishable from growth in solution 1.

Growth enhancement in solution 2 was achieved with the addition of Ca as a chloride, sulfate, or carbonate salt (Figure 4). However, in examining possible implications of the nearly threefold difference in solution Ca supply, tissue Ca concentrations did not differ appreciably between plants grown in solution 1 ( $\text{Ca} = 11.2 \text{ mg} \cdot \text{g}^{-1}$ ) and solution 2 ( $\text{Ca} = 9.0 \text{ mg} \cdot \text{g}^{-1}$ ). These data suggest that exogenous rather than endogenous Ca supply influenced solution-related growth differences in the MBS. Considering the positive relationship established between photosynthetic rate in *M. spicatum* and solution Ca concentration over the range of 0.3 to 9.0 mM (Stanley 1970), it is postulated that solution-related variations in the growth of this species here reflect different photosynthetic rates influenced at least partially by solution Ca concentration. This postulation is supported by the investigations of Lowenhaupt (1956), Lucas (1976), and Lucas and Dainty (1977) reporting a positive relationship between exogenous Ca concentration and the efficiency of bicarbonate transport in submersed macrophyte photosynthesis.

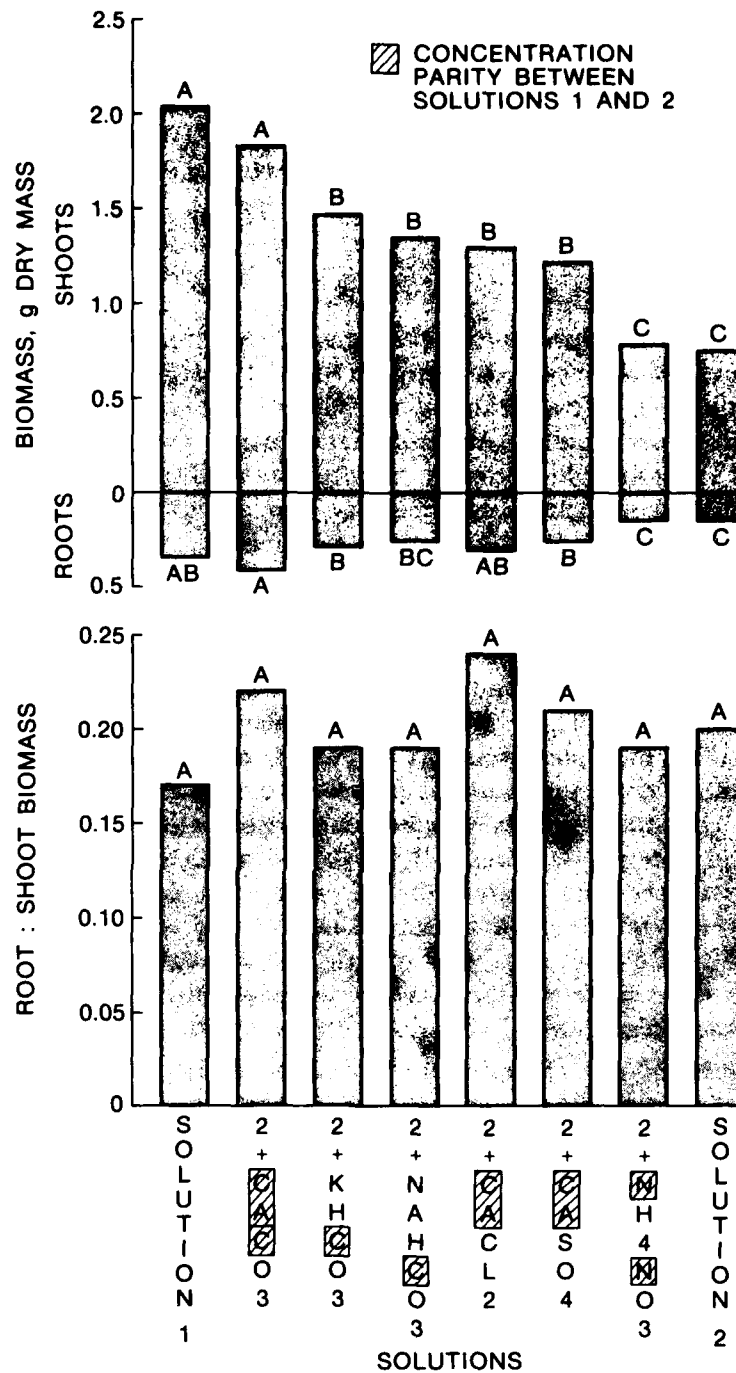


Figure 4. Total biomass production and root-to-shoot biomass ratios in *M. spicatum* grown in solutions of altered ionic composition. Alterations include additions of single salts to solution 2 in order to achieve concentration parity with selected elements (Ca, C, and N) in solution 1

In addition to Ca, other cations (monovalent and divalent) have been demonstrated to both positively and negatively mediate bicarbonate uptake processes in submersed macrophytes (Lucas, Spanswich, and Dainty 1978 and literature cited therein). It is difficult to separate the influence of cations from inorganic carbon on macrophyte growth when both covary either naturally or experimentally. Accordingly, increased growth due to additions of bicarbonate salts in this investigation could reflect increased inorganic carbon availability, cation-associated increases in bicarbonate transport efficiency, or a combination of both. The later alternative is likely to account for the relatively greater growth of *M. spicatum* associated with  $\text{CaCO}_3$  compared to  $\text{CaCl}_2$  and  $\text{CaSO}_4$  additions in this investigation.

As noted in Hutchinson (1970), there are at least four aqueous parameters that vary in a correlative way in affecting physiological processes in submersed macrophytes: pH, calcium concentration, bicarbonate concentration, and total electrolyte content. The relationship between dissolved inorganic carbon availability (dependent upon both concentration and pH) and photosynthetic rate in submersed macrophytes has been a subject of several detailed investigations in recent years (Raven 1970; Adams, Guilizzoni, and Adams 1978; Allen and Spence 1981; Beer and Wetzel 1981; Titus and Stone 1982). Considering results of the present study and corroborative literature cited above, the photosynthetic capacity of many submersed macrophytes is clearly dependent upon solution cation composition as well as inorganic carbon availability. Since inorganic carbon-cation relations may not always be correlative (due to differences in watershed geochemistry or in systems affected by industrial inputs), the independent effects of major cations on macrophyte growth rates need to be carefully evaluated.

## CONCLUSIONS

Among different aquatic systems and between locations within a single system, variations in the nature of bottom sediments undoubtedly influence macrophyte growth rates and distributional patterns. This conclusion is supported by numerous investigations of distribution of a variety of submersed macrophyte species (Pond 1905; Pearsall 1920; Wilson 1935; Misra 1938; Moyle 1945; Anderson 1978; Sand-Jensen and S ndergaard 1979). However, the dramatic influence of solution ionic composition on the sediment-related range in growth of *M. spicatum* noted here suggests that, in nature, the open water may interact with sediment in determining the growth of this species. This interaction needs to be carefully considered in evaluating variations in the productivity and distribution of submersed macrophytes.

## ACKNOWLEDGMENTS

The assistance of WES personnel Dwilette Hardin and M. Susan Matthews for their many labors in the conduct of this investigation is most appreciated. Michael Smart constructively reviewed the manuscript and contributed to the development of some of the viewpoints expressed herein. Derrick Bates is acknowledged for his statistical assistance and Jerry Jones and his analytical laboratory staff for their diligence in performing nutrient analyses. Financial support was provided by the U.S. Army Corps of Engineers Aquatic Plant Control Research Program. This article is a nearly exact duplication of an article to be published in the journal *Aquatic Botany*.

## REFERENCES

- Adams, M. S., Guilizzoni, P., and Adams, S. 1978. "Relationship of Dissolved Inorganic Carbon to Macrophyte Photosynthesis in Some Italian Lakes," *Limnology and Oceanography* Vol 23, pp 912-919.
- Allen, E. D., and Spence, D. H. N. 1981. "The Differential Ability of Aquatic Plants to Utilize the Inorganic Carbon Supply in Fresh Waters," *The New Phytologist*, Vol 87, pp 269-283.
- Anderson, M. G. 1978. "Distribution and Production of Sago Pondweed (*Potamogeton pectinatus* L.) on a Northern Prairie Marsh, *Ecology*, Vol 59, pp 154-160.
- Barko, J. W. 1982. "Influence of Potassium Source (Sediment vs. Open Water) and Sediment Composition on the Growth and Nutrition of a Submersed Freshwater Macrophyte," *Aquatic Botany*, Vol 12, pp 157-172.
- Barko, J. W., and Smart, R. M. 1979. "The Nutritional Ecology of *Cyperus esculentus*, An Emergent Aquatic Plant, Grown on Different Sediments," *Aquatic Botany*, Vol 6, pp 13-28.
- Barko, J. W., and Smart, R. M. 1980. "Mobilization of Sediment Phosphorus by Submersed Freshwater Macrophytes," *Freshwater Biology*, Vol 10, pp 229-238.
- Barko, J. W., and Smart, R. M. 1981a. "Comparative Influences of Light and Temperature on the Growth and Metabolism of Selected Submersed Freshwater Macrophytes," *Ecological Monographs*, Vol 51, pp 219-235.
- Barko, J. W., and Smart, R. M. 1981b. "Sediment-Based Nutrition of Submersed Macrophytes," *Aquatic Botany*, Vol 10, pp 339-352.
- Beer, S., and Wetzel, R. G. 1981. "Photosynthetic Carbon Metabolism in the Submerged Aquatic Angiosperm *Scirpus subterminalis*," *Plant Science Letters*, Vol 21, pp 199-207.
- Carpenter, S. R., and Adams, M. S. 1977. "The Macrophyte Tissue Nutrient Pool of a Hardwater Eutrophic Lake: Implications for Macrophyte Harvesting," *Aquatic Botany*, Vol 3, pp 239-255.
- Chapin, F. S. 1980. "The Mineral Nutrition of Wild Plants," *Annual Review of Ecology and Systematics*, Vol 11, pp 233-260.

- Clarkson, D. T., and Hansen, J. B. 1980. "The Mineral Nutrition of Higher Plants," *Annual Review of Plant Physiology*, Vol 31, pp 239-298.
- Davies, G. J., and Brinson, M. M. 1980. "Responses of Submersed Vascular Plant Communities to Environmental Change," Report No. FWS/OBS-79/33, U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C.
- Denny, P. 1972. "Sites of Nutrient Absorption in Aquatic Macrophytes," *Journal of Ecology*, Vol 60, pp 819-829.
- Drew, M. C., and Lynch, J. M. 1980. "Soil Anaerobiosis, Microorganisms, and Root Function," *Annual Review of Phytopathology*, Vol 18, pp 37-66.
- Gerloff, G. C. 1975. "Nutritional Ecology of Nuisance Aquatic Plants," National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, Corvallis, Oreg.
- Hutchinson, G. E., 1970. "The Chemical Ecology of Three Species of *Myriophyllum* (Angiospermae, Haloragaceae)," *Limnology and Oceanography*, Vol 15, pp 1-5.
- Kiørboe, T. 1980. "Distribution and Production of Submerged Macrophytes in Tipper Grund (Ringkøbing Fjord, Denmark), and the Impact of Waterfowl Grazing," *Journal of Applied Ecology*, Vol 17, pp 675-687.
- Lowenhaupt, B. 1956. "The Transport of Calcium and Other Cations in Submerged Aquatic Plants," *Biological Reviews*, Vol 31, pp 371-395.
- Lucas, W. J. 1976. "The Influence of  $\text{Ca}^{2+}$  and  $\text{K}^+$  on  $\text{H}^{14}\text{CO}_3$  Influx in Internodal Cells of *Chara corallina*," *Journal of Experimental Botany*, Vol 27, pp 32-42.
- Lucas, W. J., and Dainty, J. 1977. " $\text{HCO}_3^-$  Influx Across the Plasmalemma of *Chara corallina*: Divalent Cation Requirement," *Plant Physiology*, Vol 60, pp 862-867.
- Lucas, W. J., Spanswick, R. M., and Dainty, J. 1978. " $\text{HCO}_3^-$  Influx Across the Plasmalemma of *Chara corallina*: Physiological and Biophysical Influence of 10 mM  $\text{K}^+$ ," *Plant Physiology*, Vol 61, pp 487-493.
- Misra, R. D. 1938. "Edaphic Factors in the Distribution of Aquatic Plants in the English Lakes," *Journal of Ecology*, Vol 26, pp 411-451.
- Moeller, R. E. 1978. "Seasonal Changes in Biomass, Tissues Chemistry, and Net Production of the Evergreen Hydrophyte, *Lobelia dortmanna*," *Canadian Journal of Botany*, Vol 56, pp 1425-1433.
- Moyle, J. B. 1945. "Some Chemical Factors Influencing the Distribution of Aquatic Plants in Minnesota," *American Midland Naturalist*, Vol 34, pp 402-420.
- Nichols, H. W., and Bold, H. C. 1965. "*Trichosarrina polymorpha* gen. et sp. nov." *Journal of Phycology*, Vol 1, pp 34-38.
- Patterson, K. J., and Brown, J. M. A. 1979. "Growth and Elemental Composition of the Aquatic Macrophyte *Lagarosiphon major* in Response to Water and Substrate Nutrients," *Progress in Water Technology*, Vol. 2, pp 231-246.
- Pearsall, W. H. 1920. "The Aquatic Vegetation of the English Lakes," *Journal of Ecology*, Vol 8, pp 163-199.
- Peltier, W. H., and Welch, E. B. 1970. "Factors Affecting Growth of Rooted Aquatic Plants in a Reservoir," *Weed Science*, Vol 18, pp 7-9.

- Peverly, J. H. 1980. "Elemental Distribution and Macrophyte Growth Downstream from an Organic Soil," *Aquatic Botany*, Vol 7, pp 319-338.
- Pond, R. H. 1905. "The Relation of Aquatic Plants to the Substratum," Report of the U.S. Fish Commission, Vol 19, pp 483-526.
- Raven, J. A. 1970. "Exogenous Inorganic Carbon Sources in Plant Photosynthesis," *Biological Review*, Vol 45, pp 167-221.
- Rich, P. H., Wetzel, R. G., and Thuy, N. V. 1971. "Distribution, Production, and Role of Aquatic Macrophytes in a Southern Michigan Marl Lake," *Freshwater Biology*, Vol 1, pp 3-21.
- Sand-Jensen, K., and Søndergaard, M. 1979. "Distribution and Quantitative Development of Aquatic Macrophytes in Relation to Sediment Characteristics in Oligotrophic Lake Kalgaard, Denmark," *Freshwater Biology*, Vol 9, pp 1-11.
- Sculthorpe, C. D. 1967. *The Biology of Aquatic Vascular Plants*, St. Martin's Press, New York.
- Spence, D. H. N. 1967. "Factors Controlling the Distribution of Freshwater Macrophytes, With Particular Reference to Scottish Lochs," *Journal of Ecology*, Vol 55, pp 147-170.
- Stanley, R. A. 1970. "Studies on Nutrition, Photosynthesis, and Respiration in *Myriophyllum spicatum* L.," Ph. D. Thesis, Duke University, Durham, N. C.
- Titus, J. E., and Stone, W. H., 1982. "Photosynthetic Response of Two Submersed Macrophytes to Dissolved Inorganic Carbon Availability," *Limnology and Oceanography*, Vol 27, pp 151-160.
- Wetzel, R. G. 1979. "The Role of the Littoral Zone and Detritus in Lake Metabolism," *Archiv für Hydrobiologie*, Vol 13, pp 145-161.
- Wilson, L. R. 1935. "Lake Development and Plant Succession in Vilas County, Wisconsin: Part I. The Medium Hard Water Lakes," *Ecological Monographs*, Vol 5, pp 207-247.

# ECOLOGY OF GIANT CUTGRASS (*ZIZANIOPSIS MILIACEA*) IN LAKE SEMINOLE

by  
R. Michael Smart\* and John W. Barko\*

## BACKGROUND

Giant cutgrass is an emergent aquatic plant usually found in shallow fresh or brackish waters bordering lakes or streams. The species spreads rapidly through waterborne transport of seeds and eroded plants as well as by production of rhizomes and stolons. Cutgrass has spread throughout the Flint and Chattahoochee arms of Lake Seminole resulting in nearly complete cover of the shoreline. The areal coverage of cutgrass in Lake Seminole has been recently estimated at 2300 hectares, or 15 percent of the total lake surface.

Problems associated with excessive growth of cutgrass include closure of small boat channels by vegetative growth and increased sedimentation, resulting in rapid decreases in water depth and lake surface. Established stands expand by extension of stolons into open water. Plants originate at each node along the length of the stolon (often several metres) and are capable of growing in water depths up to 1 m. In order to prevent closure of small boat channels, control of vegetative extension into open water should be practiced annually. Removal of cutgrass from the shoreline would seem to be the most expedient method of maintaining navigable channels; however, these efforts are often thwarted by rapid regrowth or reinvasion of cleared areas. Because of the generally shallow nature and irregular morphometry of Lake Seminole, the growth and associated spread of cutgrass will likely continue at a high rate.

## OBJECTIVES AND APPROACH

The objectives of this 5-year work unit are to assess the potential future distribution of cutgrass in Lake Seminole and to assist in the development and implementation of a cutgrass control program. In order to complete these objectives, it is necessary to determine the factors allowing giant cutgrass to exploit the available habitat so completely. Once this competitive advantage has been identified, the reservoir may be "managed" to provide conditions more favorable to the establishment of other, more desirable species. This approach will allow the development of control and replacement techniques that should minimize the necessity for continuous control programs. Without this information, control measures are likely to provide only short-term relief.

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## RESEARCH RESULTS

The objectives of the first year (FY 81) effort were:

- a. Examine cutgrass growth and distribution in Lake Seminole.
- b. Develop cutgrass sampling and related analytical techniques.
- c. Initiate sediment sampling and related chemical analyses.
- d. Develop a detailed plan of study concerning the biology of cutgrass in Lake Seminole.

The first three objectives were accomplished during a sampling survey of cutgrass distribution in Lake Seminole. Samples of leaf tissue and sediments as well as data on plant height, density, and water depth were collected from a number of sites located in the main pool and each of the four arms of Lake Seminole during 23-28 August 1981. A preliminary summary of general observations follows.

At present, the distribution of cutgrass is limited to the main pool and the Chattahoochee and Flint arms. Only a few small, isolated patches were observed along Spring Creek and Fish Pond Drain. The reasons for the disjunct distribution are presently unknown, but may, in part, be attributed to the lack of a source of propagules in the upper reaches of Spring Creek and Fish Pond Drain.

Cutgrass appears to grow on a wide range of sediment textures but achieves greatest development on coarse-textured sediments in areas adjacent to flowing water. Inland stands are shorter in stature and often exhibit a chlorotic appearance. These observations suggest that cutgrass satisfies a portion of its nutritional requirements from the water.

Many highly developed stands produce a dense network of heavily rooted, floating shoots. These shoots eventually reach sufficient mass to sink to the sediment surface and subsequently develop roots into the sediment and promote sedimentation in the dense root mat. During this progression, the advancing plants may obtain their nutrition from the existing stand, from the water, and, finally, from the sediment. This growth pattern may contribute to the rapid spread of cutgrass into open water.

A large number of cutgrass seedlings were observed in many areas of the Lake in water depths of 25 cm or less. These seedlings may be contributing to the rapid spread of the species, particularly during low water years (such as 1981). Seed collected during the survey exhibited a low level of germination immediately after collection. The possible enhancement of germination by cold storage will be examined later.

Field plots were established at Lake Seminole in the spring of 1981 to evaluate the effects of harvesting or burning on subsequent regrowth. Early spring clipping at the sediment surface (under water) followed by a second clipping in early summer only slightly diminished plant stature attained by August of the same year. Observation of a burned area likewise revealed little effect on subsequent regrowth. These results suggest that aboveground harvesting may delay, but not impede, further spread of cutgrass.

Observation of a number of sites that had been subjected in prior years to various control measures (chemical, mechanical, or both) revealed complete reestablishment of cutgrass.

A few emergent aquatic plant species were observed to establish monospecific stands or to coexist with cutgrass (notably *Typha* spp. and *Colocasia esculentum*, respectively). Cutgrass does not appear to be invading *Typha* stands at this time. These observations suggest that control measures followed by planting of more desirable species might be effective in diminishing or preventing the further encroachment of cutgrass into the lake.

### FUTURE RESEARCH

Data obtained during the 1981 survey will be analyzed to identify environmental variables potentially affecting the growth of cutgrass. Greenhouse investigations of the responses of cutgrass (and several potential competitors) to these selected variables will be conducted. Upon completion of these studies, several replacement species will be selected and their performance in field test plots will be evaluated. Competition studies will be conducted at Lake Seminole to evaluate the feasibility of replacing cutgrass with other more desirable species.

# **PROBLEM IDENTIFICATION AND ASSESSMENT FOR AQUATIC PLANT MANAGEMENT**

by  
Barry Payne\*

## **BACKGROUND**

Initial planning as well as subsequent implementation, monitoring, evaluation, and modification of aquatic plant control operations requires the capability to identify and assess the scope of actual and potential plant infestations. Also useful is a capability to classify infested areas into categories related to the best available control methods. Quantification of the impacts and benefits of aquatic plant control operations is equally desirable. The Problem Identification and Assessment Work Unit of the Aquatic Plant Control Research Program (APCRP) is conducting research to develop these capabilities.

## **APPROACH**

Studies being performed are aimed at accomplishing four tasks designed to develop regional and site-specific methods. These tasks are:

- Task 1: Map the distribution and abundance of emergent, floating, and submerged aquatic macrophytes.
- Task 2: Classify habitats according to their potential for supporting problem infestations of aquatic macrophytes.
- Task 3: Classify sites with problem infestations of aquatic plants according to the most efficacious available control methods.
- Task 4: Quantify the economic and social impacts and benefits of aquatic plant control.

## **CURRENT STATUS**

### **Task 1 studies**

Task 1 studies constitute most of the research under the Problem Identification and Assessment Work Unit performed to date. These studies have shown that the combination of aerial photography and limited ground surveys is generally the most rapid, accurate, and cost-effective approach to regional and site-specific mapping of the distribution and abundance of emergent, floating, and submerged aquatic macrophytes. Dardeau (1982) presents case histories of typical uses of this approach.) Some habitats are more easily mapped using only ground surveys. Small rivers overhung by trees as well as small lakes and ponds adjacent to the home base of ground survey crews fall into this second category.

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Determinations that should be made prior to planning any remote sensing mission (Struve and Kirk 1980) are:

- a. Format and scale of final products.
- b. Type of interpretation required.
- c. Selection of appropriate altitude, time of day, and time of year.
- d. Determination of solar altitude and maximum acceptable cloud cover and shape.
- e. Selection of camera and optimum film/filter combination.

These determinations already have been made to allow planning of most aerial photographic surveys of aquatic plants. Studies funded entirely or in part by the Problem Identification and Assessment Work Unit led to these technical determinations. These studies are detailed elsewhere (Rekas 1981; Dardeau 1982; and references within both of these). Also, Leonard's paper beginning on page 170 of the present proceedings describing studies performed for the Galveston District summarizes many of these conclusions.

Current efforts in Task 1 are directed at producing a handbook on aerial photography of aquatic macrophytes. This handbook will provide guidance for accomplishing the following planning phases:

- a. Identification of target species and areas.
- b. Review of available imagery coverage.
- c. Review of sources from which imagery can be obtained.
- d. Mission specification.
- e. Quality control.
- f. Photointerpretation and map production.

## **Task 2 studies**

These ecological studies will attempt to determine which environmental factors are associated with observed distributions of aquatic macrophytes. These field investigations will augment recent APCRP-funded laboratory investigations of the physiological ecology of submerged aquatic plants (Barko 1981; and references within). Fundamental insights into habitat requirements of submerged plants have been provided by these laboratory investigations. These insights will be used to plan field investigations to see if environmental factors that critically influence plant growth in the laboratory are related to differences in the abundance of submerged plants.

An initial field investigation of the distribution of Eurasian watermilfoil in Lake Osoyoos, Washington (see Rekas (1981) for details), suggests that the distribution of this submerged plant is not associated with the elemental composition, texture, or total nutrient contents of bottom sediments. Winddriven waves appear to determine the overall distribution of submerged plants in this lake. The chemical

constituency of interstitial water among the sediment particles may explain smaller scale differences in the abundance of submerged plants in Lake Osoyoos. Investigations of these possible associations are scheduled for 1982.

### **Task 3 studies**

A conceptual framework for classifying sites with problem infestations of aquatic macrophytes according to the most efficacious available control methods will be completed during 1982. This framework consists of five sequential phases, each having several steps. The five phases are:

- I. Definition of a standard measure of treatment efficacy.
- II. Description of relationships of method attributes to efficacy.
- III. Description of relationships of site variables to efficacy via affected method attributes.
- IV. Establishment of a site classification system for prediction of treatment efficacy.
- V. Site- and control-method-specific predictions of treatment efficacy.

Studies in 1982 will be aimed at identifying site variables that affect treatment efficacy.

### **REFERENCES**

- Barko, J. W. 1981. "Influence of Sediment on the Growth and Nutrition of Submersed Freshwater Macrophytes," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review; 17-20 November 1980, Savannah, Georgia*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Dardeau, E. A., Jr. 1982. "Remote-Sensing Procedures Applied to Mapping and Monitoring Aquatic Plant Population; Four Case Studies," Technical Report (in preparation), U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Rekas, A. M. B. 1981. "Problem Identification and Assessment; An Overview," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review; 17-20 November 1980, Savannah, Georgia*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Struve, H., and Kirk, W. L. 1980. "Remote-Sensing Procedures for Detecting and Monitoring Various Activities Regulated by the Mobile District," Technical Report EL-80-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

# BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

## An Overview

by  
Dana R. Sanders, Sr.\*

Biological control involves the use of one species to limit the population development of another species. Although many types of organisms may act as biocontrol agents, we will focus our presentations during this session on insects and plant pathogens for the biocontrol of aquatic plants.

The purpose of the research being conducted under the biological control technology development element of the Aquatic Plant Control Research Program (APCRP) is to accelerate the development of the capability for using biological agents for the control of troublesome aquatic plant species. The successful completion of this research is expected to result in the availability of new aquatic plant management tools that are both economical and environmentally compatible. It is also expected to result in the development of management strategies that will produce the maximum possible level of biocontrol within the framework of currently employed management programs.

## TARGET PLANT SPECIES

The development of biocontrol technology for aquatic plant management has focused on four plant species: alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb); waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.); hydrilla (*Hydrilla verticillata* (L. F.) Royle); and Eurasian watermilfoil (*Myriophyllum spicatum* L.).

## APPROACH

The development of a biocontrol agent as an effective aquatic plant management tool involves five distinct tasks, including:

- I: Discovery of candidate biocontrol agents.
- II: Host specificity and efficacy studies.
- III: Obtaining permission for release.
- IV: Release and establishment of biocontrol agents.
- V: Management of biocontrol agents.

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### Task I

This task involves both domestic and overseas searches for candidate biocontrol agents. As a result of domestic surveys, the fungal plant pathogen *Cercospora rodmanii* Conway was found on waterhyacinth. Overseas searches in the region where the target plants evolved have resulted in the discovery of three insect species on alligatorweed and three insect species on waterhyacinth (see below).

Scientific Name	Common Name
<b>Alligatorweed</b>	
<i>Agasicles hygrophila</i> Selmon and Vogt	Alligatorweed flea beetle
<i>Amylothrips andersonii</i> O'Neil	Alligatorweed thrips
<i>Vogtia malloi</i> Pastrana	Alligatorweed stem-borer
<b>Waterhyacinth</b>	
<i>Neochetina eichhorniae</i> Warner	Mottled waterhyacinth weevil
<i>Neochetina bruchi</i> Hustache	Chevroned waterhyacinth weevil
<i>Sameodes alboguttalis</i> Warner	Waterhyacinth moth

Overseas searches are currently under way in Africa and Asia for candidate biocontrol agents on hydrilla, and these efforts will be discussed by Dr. Balciunas. Although several insect species have been found to infest Eurasian watermilfoil in eastern Europe and Asia, none have proven to be viable candidate biocontrol agents.

### Task II

When a candidate biocontrol agent has been discovered, several years must be spent determining its degree of host specificity and impact on the host plant. First, feeding trials are conducted in the country of origin to determine its range of potential hosts. Results of these tests are used to develop a petition for the introduction of the candidate biocontrol agent into quarantine in the United States. If approved by the USDA Animal and Plant Health Inspection Service (APHIS), the candidate biocontrol agent is then subjected to additional feeding trials in quarantine. Efficacy studies are also conducted.

### Task III

When the quarantine research has been completed, a second petition must be submitted to APHIS requesting permission to release the biocontrol agent from quarantine. This petition includes the results of all feeding trials and efficacy studies, as well as information pertaining to the biology of the candidate biocontrol agent. In some cases, additional studies or information may be required by APHIS.

### Task IV

When approval for release from quarantine has been obtained, the biocontrol agent must be established on the target plant species. For some species, this requires no more than transporting a few adults to release points scattered

throughout the U.S. range of the target plant. This has proven to be the most effective method for establishing the alligatorweed flea beetle and the two species of waterhyacinth weevils. In other cases, additional research may be necessary to develop suitable methods for releasing and establishing the biocontrol agents. This is especially true for moths, in which the adults are fragile and ephemeral. In such cases, the releases are usually made by releasing eggs or larvae. The Argentine waterhyacinth moth has proven to be especially difficult to establish.

#### **Task V**

Once the biocontrol agents have become established on the target plant, they will begin to disperse to other areas containing suitable populations of the target plant. For species with short life cycles and great mobility, dispersal to surrounding areas may occur rapidly. In such cases, no further initial management efforts may be needed. For species with longer life cycles (e.g., waterhyacinth weevils) or limited mobility (e.g., alligatorweed thrips), it may be necessary to use the initial release sites as nursery areas to supply insects for additional releases. In addition to determining the need to actively disperse the biocontrol agents in the area of interest, other management efforts are necessary. Research is needed to determine the level of control provided by the biocontrol agents. If the agents fail to provide the desired level of control, efforts must be undertaken to determine the factors limiting their effectiveness. Also, when it is evident that a biocontrol agent is providing significant control of the target plant, consideration must be given to its use in relation to other control measures being employed. Because biological control is generally much less costly than most other methods, the biocontrol agents should be incorporated into existing management programs in such a way as to gain the maximum benefits from the biocontrol agents while meeting the operational objectives of the management plan.

### **CURRENT BIOLOGICAL CONTROL RESEARCH**

The current biological control research efforts address each of the five tasks discussed above. As you will hear in the following presentations, we are actively searching for candidate biocontrol agents, conducting host specificity and efficacy studies, preparing petitions for release of organisms from quarantine, releasing approved biocontrol agents, and developing management strategies for their use. The success of this overall research effort to date is reflected in the greatly reduced population of alligatorweed in the southeastern states as a result of the impacts of the three species released during the early 1970's. More recently, the waterhyacinth weevils have contributed significantly to the nearly 1-million-acre reduction in the waterhyacinth population that has occurred in Louisiana. To put this into monetary terms, it would require between \$20 and \$30 million to achieve such a reduction in the waterhyacinth population in Louisiana by a one-time application of 2,4-D. We have estimated that the per acre cost of using these agents is about \$2.20/acre, including all research efforts.

# BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

## Investigations of *Parapoynx* spp. for Biocontrol\*

by  
Gary R. Buckingham\*\*

*Parapoynx* is a genus of aquatic moths, several species of which have been of interest for their biological control potential. Last year in Savannah, I reported that I had initiated quarantine studies on *Parapoynx rugosalis* (Möschler) (Buckingham 1980). One specimen of *P. rugosalis*, a Caribbean species, was reared from larvae collected on hydrilla at Gatun Lake, Panama, in 1979. Since the host plants of *P. rugosalis* were unknown and since the larvae were apparently causing considerable damage to hydrilla, larval starvation tests were conducted in Panama in May 1980 (Balciunas and Center 1981). Based upon the results of those tests, I received permission to import *P. rugosalis* into quarantine for further testing. Late in October 1980, larvae and adults, collected on hydrilla in Panama went to Gainesville. I then began studies of the biology and host specificity. This population was later identified as *P. diminutalis* (Snellen) (Figure 1) by Dr. D. Ferguson, Systematics Entomology Laboratory, Washington. The adults captured during the larvae collection for the host specificity tests were a third, as yet unidentified, species. The similarity of this unidentified species to *P. diminutalis*



Figure 1. *Parapoynx diminutalis* (Snellen) male

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\*This paper was presented by Joseph K. Balciunas at the meeting.

\*\*Biological Pest Control Research Unit, U.S. Department of Agriculture, Gainesville, Florida.

suggests that it is probably also an Asian species accidentally introduced into Panama. Another effort to obtain *P. rugosalis* in Panama was made by Dale Habeck, University of Florida, in August 1979, as he was returning from Central America, but again all adults and larvae were *D. diminutalis*. Probably the best explanation to this mystery of the missing species is that the three species differ in their seasonality. *Parapoynx diminutalis* would be the dominant species from at least August to November. It is hard to imagine that *P. diminutalis* has replaced the other two species when there is such an abundance of the host plant hydrilla.

The species from Panama that we tested in quarantine, *P. diminutalis*, was discovered at Fort Lauderdale in 1976 (Del Fosse, Perkins, and Steward 1976). Undoubtedly, it had been accidentally introduced with aquarium plants since it has been reported to cause appreciable damage in an aquatic nursery in England and has been collected from an aquatic nursery in Denmark (Agassiz 1981). Prior to its discovery in Fort Lauderdale, it had been the subject of preliminary testing in both Pakistan and India as a potential biocontrol agent for the United States, but had been dropped from consideration due to lack of larval specificity. Because of the apparent lack of specificity, no attempts were made to aid the distribution in Florida; however, it has now spread at least as far north as near Tallahassee, Florida (Balciunas and Habeck 1981). Interestingly, although it is abundant in some locations on hydrilla, only a few specimens have been collected from another host, southern naiad.

The eggs of *P. diminutalis* are deposited in batches on the leaves of hydrilla at the water's surface. Although the female may insert her abdomen into the water, most of her body remains above the surface, unlike another aquatic moth, *Acentria nivea* (Olivier), which may enter the water to oviposit on Eurasian watermilfoil (Buckingham and Ross 1981). The newly emerged *P. diminutalis* larvae feed by scraping the leaf's surface. They may construct a shelter by cutting a small piece from the leaf margin and fastening it to the leaf's surface or else they may feed without a shelter. This first stage does not have the feathery gills nor the dark head spots found on the second and older stages. The second and older stages usually construct tubular cases from small pieces of leaf and carry the cases with them as they feed on the leaves and stems (Figure 2). These older larvae have characteristic dark spots on their heads that separate them from the native *Parapoynx* larvae, which are not spotted. For personnel working in the Gulf States this would be an easy identifying character to remember, and may be useful in the future if *P. diminutalis* spreads outside of Florida. A silken cocoon covered with leaf fragments is made on the stem and the pupa inside the cocoon obtains oxygen from the stem. In areas such as northern Florida where the hydrilla stems break apart during the winter, there appears to be heavy mortality of the pupae on the stem fragments, possibly due to a lack of oxygen or to low temperatures.

The adults emerge in the early evening, mate, and begin ovipositing the same night. They live in the laboratory for only a few days. The larval-pupal period on hydrilla in the laboratory varied from 15 to 66 days depending upon the water temperature. Constant temperatures below about 20° C and above 37° C were



Figure 2. *Parapoynx diminutalis* larval case on hydrilla stem

lethal; however, larvae survived short exposure to both these extremes under the varying temperature regimen of a greenhouse. The average length of the larval-pupal period was 20 to 30 days at temperatures between 26° to 31° C, which appeared to be the most optimum constant temperatures. Excellent survival and low generation times were obtained with varying temperature regimens that had night lows of about 22°C (8 hr) and day highs of 31° to 33°C (16 hr).

Larval host specificity tests confirmed the results of previous researchers that *P. diminutalis* would feed and develop on species in the genera *Vallisneria*, *Najas*, *Nymphaea*, and *Potamogeton* in addition to hydrilla (Baloch and Sana-Ullah 1973; Sankaran and Rao 1972). Plant species that produced at least one laboratory generation of *P. diminutalis* are listed below. I obtained at least one laboratory generation on the plant species listed and multiple generations on many of them.

*Cabomba pulcherrima*  
*Ceratophyllum demersum*  
*Egeria densa*  
*Eleocharis* sp.  
*Hydrilla verticillata*  
*Hygrophila* sp.  
*Myaca fluvialis*  
*Myiophyllum spicatum*

*M. heretophyllum*  
*Najas guadalupensis*  
*Nymphaea odorata*  
*Nymphaea* sp. (Asian)  
*Polygonum densiflorum*  
*Potamogeton illinoensis*  
*Ruppia maritima*  
*Vallisneria americana*

Adults were not obtained on *Utricularia*, but pupae were formed, suggesting that it may also be a potential host. The larvae fed upon some of the species in the following genera but no adults were obtained: *Azolla*, *Bacopa*, *Echinodorus*, *Isoetes*, *Marsilae*, *Nitella*, *Nuphar*, *Nymphoides*, *Oryza*, *Pistia*, *Proserpinaca*, *Rorippa*, *Sagittaria*, and *Salvinia*.

When both newly emerged and older larvae had a choice between hydrilla and another acceptable plant species, they generally chose hydrilla; however, the results were often variable. The results of oviposition choice tests were also variable, with cabomba and coontail generally preferred over hydrilla.

These test results indicate the *P. diminutalis* has the potential to attack many native and adventive submersed macrophytes. Possibly it is already doing so in Florida at low population levels or possibly it has a stronger preference for hydrilla in the field than it does in the laboratory. It will probably be several years before we know more about its field host range, but, in the meantime, its populations are apparently increasing in Florida and its damage in some areas is impressive. This autumn in Lochloosa Lake near Gainesville every hydrilla mat sampled had larvae and the surface stems of many mats were heavily damaged.

## REFERENCES

- Agassiz, D. 1981. "Further Introduced China Mark Moths (Lepidoptera: Pyralidae) New to Britain," *Entomologist's Gazette*, Vol 32, No. 1, pp 21-26.
- Balciunas, J. K., and Center, T. D. 1981. "Preliminary Host Specificity Tests of a Panamanian *Parapoynx* as a Potential Biological Control Agent for Hydrilla," *Environ. Entomol.*, Vol 10, No. 4, pp 462-467.
- Balciunas, J. K., and Habeck, D. H. 1981. "Recent Range Extension of a Hydrilla-Damaging Moth, *Parapoynx diminutalis* (Lepidoptera: Pyralidae)," *Florida Entomol.*, Vol 63, No. 1, pp 195-196.
- Baloch, G. M., and Sana-Ullah. 1973. "Insects and Other Organisms Associated with *Hydrilla verticillata* (L.f.) L. C. (Hydrocharitaceae) in Pakistan," *Proc. 3rd Int. Symp. Biol. Control Weeds, Montpellier, France*, pp 61-66.
- Buckingham, G. R. 1980. "Evaluation of Insect Species for Biocontrol of Aquatic Plants," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-20 November 1980, Savannah, Georgia*. Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Buckingham, G. R., and Ross, B. 1981. "Notes on the Biology and Host Specificity of *Acentria nivea* (= *Acentropus niveus*)," *Journal of Aquatic Plant Management*, Vol 19, pp 32-36.
- Del Fosse, E. S., Perkins, B. D., and Steward, K. K. 1976. "A New U.S. Record for *Parapoynx diminutalis* (Lepidoptera: Pyralidae), A Possible Biological Control Agent for *Hydrilla verticillata*," *Florida Entomol.*, Vol 59, No. 1, pp 19-20.
- Sankaran, T., and Rao, V. P. 1972. "An Annotated List of Insects Attacking Some Terrestrial and Aquatic Weeds in India, With Records of Some Parasites of the Phytophagous Insects," *CIBC Technical Bulletin No. 15*, pp 131-157.

# BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

## Distribution and Effects of *Sameodes* on Waterhyacinth

by  
Ted D. Center\*

### INTRODUCTION

Holm et al. (1977) rank waterhyacinth as eighth among the world's most serious weeds. Because it is distributed primarily in the tropics, underdeveloped countries face the greatest problems from this weed, which include interference with virtually every conceivable use of water resources (Holm 1969). Although effective herbicidal controls are available (Little 1968), these are often impractical because of the vast acreages frequently involved (Little 1965). Environmental concerns over the use of potentially toxic substances in potable water make the registration of new herbicides for use in aquatic systems difficult. Rising world oil prices have resulted in higher costs for presently available herbicidal products as well as increased application expenses. It is, therefore, desirable to reduce the present dependence upon the chemical control of aquatic weeds and, in response to this, the U.S. Department of Agriculture (USDA), in cooperation with the U.S. Army Corps of Engineers Aquatic Plant Control Research Program (APCRP) and the Florida Department of Natural Resources (FDNR), have undertaken the task of developing a program of biological control.

The early work on the biological control of aquatic weeds has been reviewed by Blackburn, Sutton, and Taylor (1969) and Andres and Bennett (1975). Surveys in South America identified several insects potentially useful for the biological control of waterhyacinth (Bennett and Zwolfer 1968; Perkins 1974) and life history studies and host specificity tests were conducted for a few of these species (Silveira-Guido and Perkins 1975; DeLoach 1976; DeLoach and Cordo 1976a,b, 1978; DeLoach et al. 1980; Cordo and DeLoach 1978; Perkins and Maddox 1976). These studies have thus far led to the release of three insect species in the United States. The first two were the weevils *Neochetina eichhorniae* Warner and *N. bruchi* Hustache, released in 1972 and 1974, respectively (Perkins and Maddox 1976; Perkins 1973). The third was the pyralid *Sameodes albiguttalis* (Warren), first released in 1977 and reported as well established by 1979 (Center and Durden 1981).

Following the initial establishment of the two weevil species, a great deal of emphasis was placed upon operational aspects of the dissemination of these insects in Florida (Zeiger 1979) and Louisiana (Manning 1979). These were extremely labor-intensive exercises by aquatic plant management agencies in which weevils were field collected or reared in greenhouses and thousands were

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released at hundreds of sites in these two states. These two species appear to be extremely slow to disperse and this effort was probably necessary to ensure a maximum dispersion of the insects in a minimum amount of time. In one 33-ha lake, for example, almost 2 years was required for *N. eichhorniae* to become relatively evenly distributed throughout the lake after the release (unpublished data).

In contrast to the *Neochetina* spp., *S. albiguttalis* disperses rapidly. Population numbers increase quickly because of their relatively short generation time and high fecundity. They also seem to be strong fliers and rapid dispersal away from release sites has been noted (Center and Durden 1981). From this early information, it appeared that an extensive operational collection and release program would not be required for the wide dissemination of this insect. The survey described in this paper was designed to determine if this speculation was accurate. Within 18 months after we first noted extensive dispersal beginning, *S. albiguttalis* had spread throughout peninsular Florida.

## METHODS AND MATERIALS

Waterhyacinth plants within the original release sites were closely examined at frequent intervals to determine the state of development of the founder populations. When pupae were first noted, adjacent sites were examined for signs of larval activity. Larvae are more likely to feed on certain forms of the plant (Center and Durden 1981), and, by concentrating on examining the proper plant morphotype, the time required to ascertain the insects presence or absence could be reduced to a manageable level.

The original 20 release sites were located in three general areas. These three areas were considered loci from which dispersal could take place. After it had been determined that some local movement of the populations had begun, zones of interception were established and waterhyacinth populations in these zones were intensively monitored for signs of the presence of *S. albiguttalis*. The oldest site was in central Florida on the Pinellas Peninsula, which is nearly surrounded by Tampa Bay and the Gulf of Mexico. The rivers which empty into the bay include the Manatee, Little Manatee, Alafia, and Hillsborough and are across the bay from the release site. Only the Manatee and Hillsborough Rivers had large aggregations of waterhyacinth. Hence, these two rivers to the east and Lake Tarpon to the north were used as monitoring areas to determine when the insects had begun to disperse away from the Pinellas Peninsula.

Most of the release sites were located in south Florida and this constituted the second of the three population loci. Populations were well established in this area and all were located south of U.S. Route 84 primarily in the extensive canal systems of the Everglades Conservation Areas. Extensive monitoring was conducted in the area north of this highway in order to determine when northward dispersal had begun.

The third population locus was in Gainesville in north-central Florida at Lake Alice on the University of Florida campus. Additional waterhyacinth populations occurred primarily to the south and east of this site. Monitoring sites included Biven's Arm, Orange, Newnans, and Lochloosa Lakes as well as Payne's Prairie and the interconnecting canal systems.

After the presence of *S. albiguttalis* was established in the interception areas, sites well in advance of the advancing population fronts were examined. The search area was thus repeatedly expanded until areas were included in which *S. albiguttalis* could not be found and which were peripheral to the known populations. When that point was determined, sites were examined from there back towards the known populations until the limits of the range of the insect were determined. Then, areas progressively farther away were reexamined more intensively to ensure that *S. albiguttalis* could not be found. Although it was not possible to test the accuracy of this system, it appeared to be very efficient and repeatable and provided a good estimate of the distributional limits of the populations.

Other sites, which were not necessarily near to known infestations of *S. albiguttalis*, were examined in a less systematic manner. These examinations were somewhat opportunistic in nature and, as time and resources allowed, as many sites as possible were examined as often as possible. This was to determine whether the insect was scattering in random pattern away from known populations rather than in a regular radial expansion.

Each site was accurately plotted on a 1:250,000-scale map of Florida and coded to the three possible results of the examinations. At any specific site, waterhyacinth may not have been present, waterhyacinth may have been present but no evidence of *S. albiguttalis* found, or both waterhyacinth and *S. albiguttalis* may have been found. After these data were plotted, a grid was superimposed on the map. The grid corresponded with the U.S. Geological Survey 7.5-min quadrangles and was identified by a coordinate system. Each quadrangle was then coded as to whether or not *S. albiguttalis* was present at any site within it and the date that its presence was first verified. At the end of the study, the coordinates and the time the insect had been present within each quadrangle were plotted as a contour map on an outline of the state using the SYMAP system (Dougenik and Sheehan 1979). The data for the north, central, and south areas of the state were mapped separately using a third-order polynomial smoothing routine. This produced isolines that estimated the limits of distribution on various dates. These contours were then transferred to the large-scale map and used to estimate dispersal rates.

In March 1980, a second survey was begun in an effort to derive quantitative information on the distribution of *S. albiguttalis* along a north-south transect that extended the entire length of the state. Ten sites were selected within  $1/2^\circ$  latitudinal intervals (Figure 1) and waterhyacinth plants were sampled on a quarterly basis in these areas. All sites were sampled within a contiguous 4- to 5-week period every 3 months over a period of 15 months. Occasionally, upon

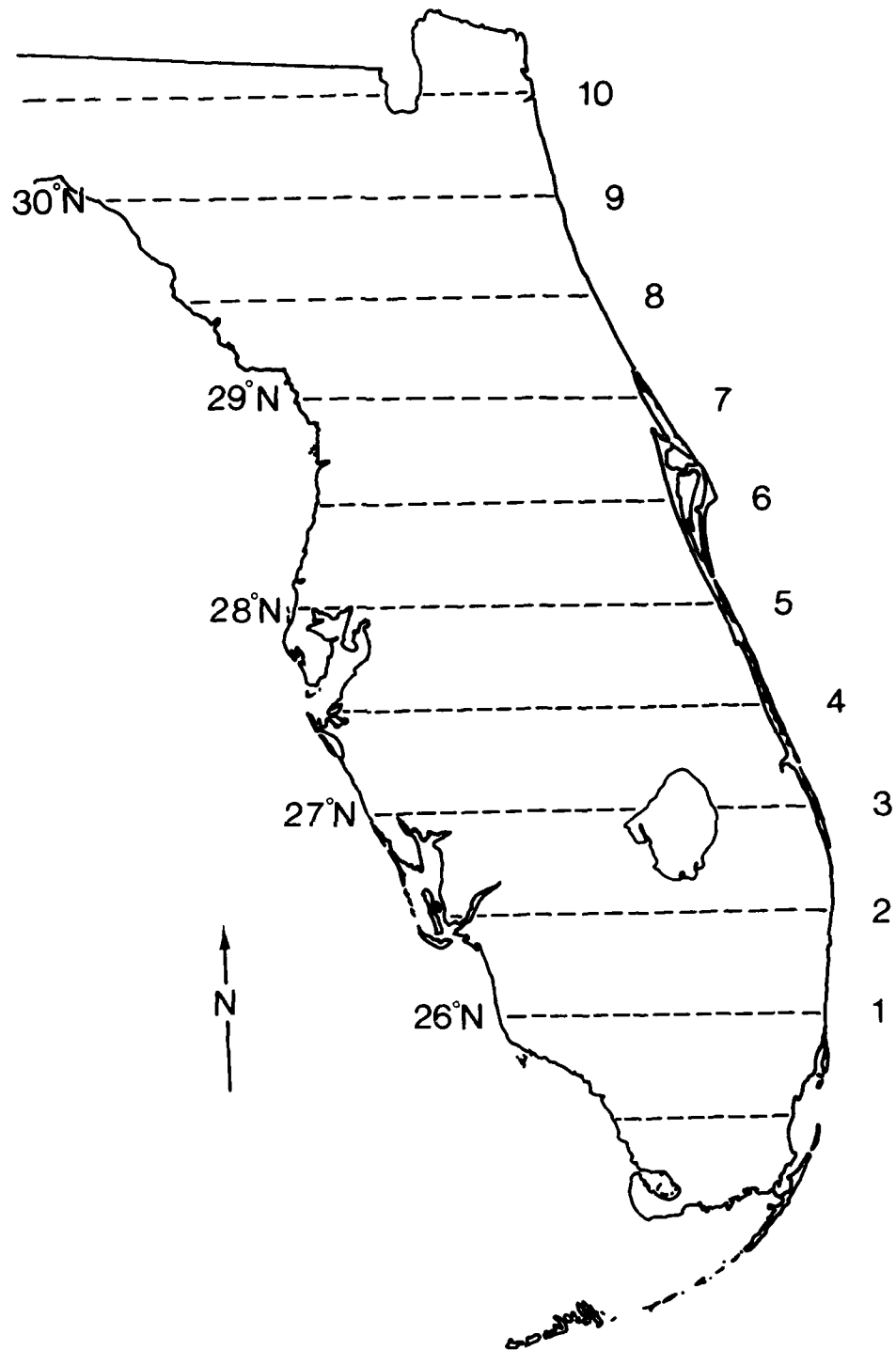


Figure 1. Map of Florida showing the location of each latitudinal zone at which quarterly quantitative estimates of the *S. albiguttalis* population intensities were derived. Sites were located predominantly along the east coast and as close to the  $1/2^\circ$  latitude interval as possible

returning to a site, the waterhyacinths would not be present. In these instances, alternative sites would be selected within the same latitudinal zone.

Samples were collected at each site by slowly piloting an airboat along the edge of the mat and manually grabbing clumps of plants at ca. 20-m intervals. The first 20 plants withdrawn from each clump were examined closely for signs of *S. albiguttalis* damage and 10 such samples were collected. Hence, at each site, an estimate of the percentage of the plants damaged based upon a total of 200 plants was derived. Based upon findings from a previous study (Center and Durden 1981), sampling was confined to areas where the plants appeared to be suitable for *S. albiguttalis* so that the data would reflect differences due to the abundances of the insects rather than the form of plant. Root length, leaf length, lamina length, lamina width, petiole length, and petiole width (Figure 2) were measured on ten plants, one randomly selected from each sample, to confirm that the plants represented similar morphotypes. The leaf measurements were always of the third youngest leaf. In addition to the original variables, the ratio of the lamina length to width, lamina length to total leaf length, root to leaf length, and petiole length to diameter were considered.

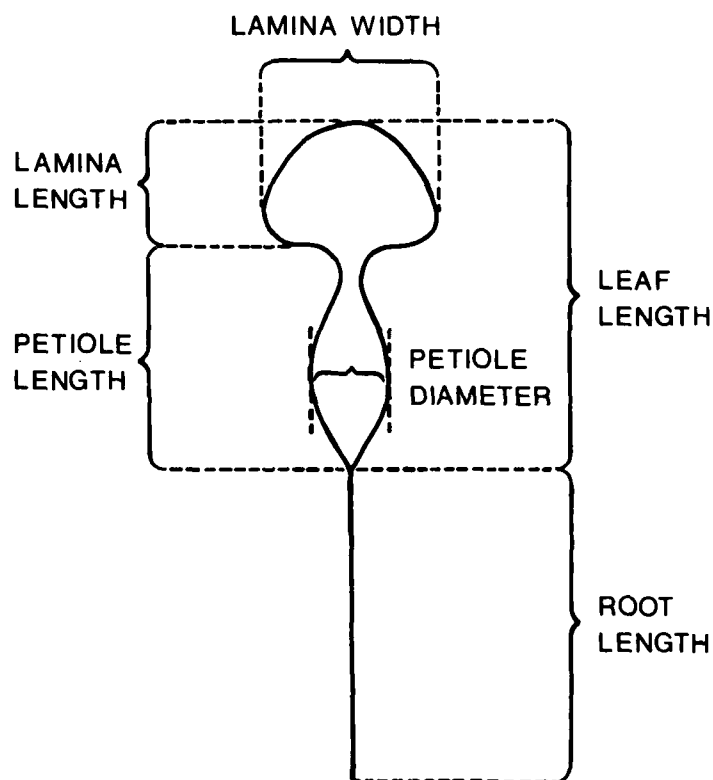


Figure 2. Schematic diagram of a waterhyacinth plant showing the leaf and root measurements used to define plant type. Measurements were of the third leaf as counted from the center of the rosette

Data were analyzed using the SAS (Barr et al. 1979) and BMDP (Dixon and Brown 1977) computer program libraries. Plant measurements were first analyzed using a multivariate analysis of variance (MANOVA) in order to obtain a simultaneous test of significance of differences among areas by season observations. Both area and season were considered as class variables. Univariate analyses of variance were also performed to compare each variable.

It became apparent during the 15-month study that it would be virtually impossible to sample uniform plant types, and the variation encountered in plant type could account for variation in damage estimates. If plants were sampled uniformly or if the majority of the variation was within a site (hereafter the term "site" will refer to a single location and date) rather than among sites, then it would not be possible to identify a site from the plant measurements. To determine if this discrimination was possible, a stepwise multivariate discriminant analysis was performed in which sites were designated as the group variable and plant measurements converted to log 10 were the classifying variables. As a prelude to this, a test of homogeneity of the within groups' covariance matrix was performed and the assumption of homogeneity of variances was confirmed.

Since the original purpose of this study was to examine seasonal and latitudinal variation in the proportion of "susceptible" plants damaged by *S. albiguttalis*, it was desirable to remove the effects of plant type from the data and thereby examine the "pure" effects of the season and latitude. Hence, the overall term "plant type" was considered a covariate and the data were analyzed as an analysis of covariance. Since six original variables and four transformed variables were necessary to define plant type, and because several of these variables were correlated, it was desirable to reduce the number of variables yet retain the intercorrelations among them. Principal axis factor analysis with varimax rotation was used to reduce the variables to a few orthogonal factors. These factors represented linear combinations of the original variables loaded in such a way as to weight a set of correlated variables within each factor. This procedure reduced the observed variables to a few nonobserved variables (comprised of subsets of the original variables), which should be manifestations of underlying factors (Sinha 1977).

Factor scores for each site were then used as indices of plant type and analyzed as covariates in a multiple linear regression procedure with latitudinal area, quarter, and a quarter by area interactions as the main effects entered as continuous variables. Also, partial correlation analysis was performed to examine the correlations between percentage damage and latitude controlling for the linear effects of quarter and plant type and between percentage damages and quarter controlling for the linear effects of latitude and plant type.

## RESULTS

Although the oldest established population of *S. albiguttalis* existed in west-central Florida on the Pinellas Peninsula, the size of the populations was

persistently small. The insects were released in this area in September and October 1977, but no evidence of their dispersal to other sites was obtained until the spring of 1979. During April and May, populations began to appear in the rivers to the east of Tampa Bay and in Tarpon Lake to the north of the peninsula. During this period of time, these west-central populations were distinctly separate from the southern or northern populations. The slow dispersal of *S. albiguttalis* away from this site was probably a result of the almost islandlike character of this area.

Because of the abundance of the suitable forms of waterhyacinth in the canal systems in the Everglades Conservation Areas, the southern populations increased rapidly. (The variation in forms of waterhyacinth is shown in Figure 3.) *Sameodes albiguttalis* was well established throughout this area and by February 1979 the range of these populations had begun to expand northward. During the spring, the movement of these populations continued northward primarily through the North New River Canal and by May they could be found at the southern end of Lake Okeechobee. By June, *S. albiguttalis* was ubiquitous throughout Lake Okeechobee. Populations had spread northward through the Kissimmee River and were present in Lake Istokpoga by July.

Because the dispersal of the southern populations was through a continuous system of canals, lakes, and rivers, the continuity of the populations was evident and their movement was relatively easily monitored. The southern and west-central populations remained disjunct up until July 1979. During the following few months, however, numerous populations began to appear throughout central Florida and by August the central and southern population fronts could no longer be distinguished and continuous populations existed throughout the southern half of the state.

*Sameodes albiguttalis* first appeared in the headwaters of the St. Johns River at Blue Cypress Lake in early July 1979. Since the St. Johns flows northward, the populations dispersed very rapidly once they reached this system, so much so that it was difficult to trace their movement accurately. By late November 1979, continuous populations occurred throughout the river from Blue Cypress Lake to Lake George and a few populations were found even farther north. One small population was found as far north as Green Cove Springs at the mouth of Black Creek, ca. 25 km south of Jacksonville, as early as 10 October. This was not surprising since waterhyacinth is a floating plant and often drifts with river currents, which would tend to accelerate the dispersal rates of the insects in a downstream direction. Several severe frosts during the winter seemed to extirpate the more northerly populations, however, and, by January 1980, the insects could not be found farther north than the southern end of Lake George. This apparent extirpation was probably due more to a loss of the plants than to the direct lethal effects of the low temperatures on the insects. By March, populations were again dispersing northward and could be found abundantly near Palatka, at Crescent Lake, and in the Ocklawaha River. In the spring of 1980, the range of populations expanded dramatically, and by July populations were present as far west as Lake City and as far north as the Nassau River near the Florida-Georgia border.

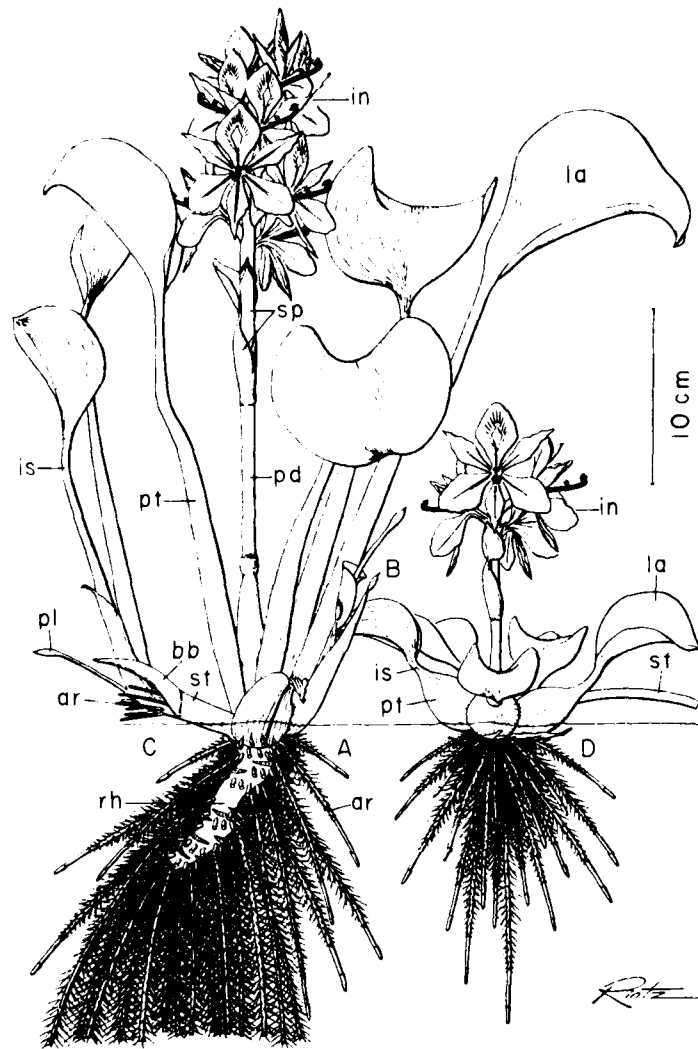


Figure 3. A generalized sketch of waterhyacinth plants showing the variation in form often encountered. Plants in dense stands tend to produce elongate petioles (A) whereas those along the fringe or in open areas tend to have inflated, bulbous petioles (D). Offsets (C) are produced from axillary buds (B). The major morphological features are: (ar) adventitious roots; (bb) bud bract or prophyllum; (in) inflorescence; (is) leaf isthmus; (la) leaf lamina; (pd) peduncle; (pl) primary leaf; (pt) leaf petiole; (rh) rhizome or stem; (sp) spathe; and (st) stolon

The northernmost release site at Lake Alice in Gainesville did not result in the establishment of widespread populations. Although the insect did persist there, the population was a very marginal one. Following the last release at this site in March 1979, nearby sites were repeatedly examined with negative results. In May 1980, however, *S. alboguttalis* was found in Orange and Newnan's Lakes and in June it

was finally found in Biven's Arm Lake, the site nearest the original release. By this time, however, populations were present throughout the northern part of the state as a result of the dispersal of the more southerly populations. It seemed likely that the insects reached these lakes by dispersing from the extensive populations in the Ocklawaha River through Orange Creek to Orange Lake and then through the connecting canals and streams to these other sites. Hence, the releases at Lake Alice probably played a minor role as a source of insects for the colonization of other sites. This was probably due to the land-locked nature of the site, the marginal suitability of the preponderance of the plants, and the resultant low insect population numbers. Hence, the site never developed a large population of insects and dispersal to other sites by those few was probably difficult.

Figure 4 shows the results of the dispersal survey with the approximate distributional limits of *S. albiguttalis* on various dates during the term of the study.

Figure 5 shows the results of the quarterly survey in terms of the proportion of the presumably susceptible plants that showed symptoms of damage by *S. albiguttalis* within each latitudinal zone. The first sampling period was during the spring of 1980 and a distinct latitudinal gradient seemed to occur at that time. Most of the plants in the southernmost areas were damaged while none in the northern areas were. Curiously, no damage was detected in the area between 29.5° and 30°N latitude. The area sampled was near Welaka on the St. Johns River and *S. albiguttalis* was known to occur in that area at that time (see Figure 4). Apparently, it was not sufficiently abundant to be found in a random sampling of plants. By the summer quarter, the relative frequency of damage had begun to decrease in the south and increase in the north. Although the numbers were low at the two northernmost sites, the insects were detectable. By the fall quarter, the latitudinal gradient had disappeared and, in fact, damage was most evident at the northernmost site. Although the presence of the insect could be detected throughout the state during each subsequent quarter, latitudinal trends were generally not evident and damage frequencies were erratic. In the spring of 1981, damage frequencies were very low in the northern areas. Several hard freezes occurred in February and had a devastating effect upon the waterhyacinth populations at these northern sites. As a result, both the plant and the insect populations were low. A massive resurgence of the plants manifested as a flush of growth occurred in the spring, which further diluted the populations. Hence, the low measure of relative damage resulted from an increase in the plant density, which caused an apparent reduction of the insects. This was generally true throughout the state but to a lesser degree in the south. Although the numbers were low in the north during the spring of 1981, the presence of *S. albiguttalis* was detectable. This contrasted with the data for the spring of 1980 when no damage was apparent in the samples north of ca. 29.5°N latitude.

Because of the lack of apparent trends in Figure 5, these data were analyzed to determine if either latitudinal and/or seasonal trends were obscured by changes in the acceptability of the plants. Although an attempt was made to sample plants that appeared to be suitable to *S. albiguttalis*, an "ideal" type could not be defined.

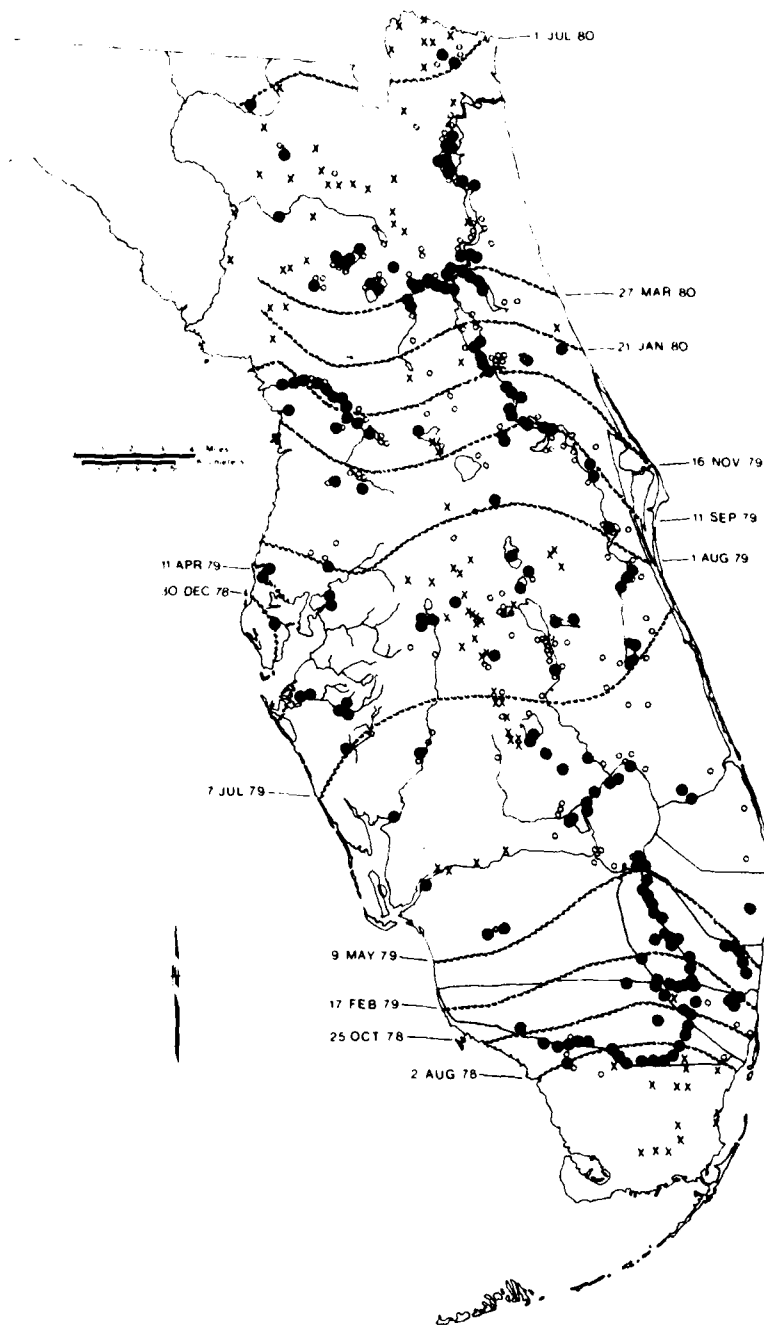


Figure 4. Map of peninsular Florida showing the distribution of *S. albiguttalis*. The closed circles represent localities where *S. albiguttalis* was found. The open circles represent localities where waterhyacinth was present but where the presence of *S. albiguttalis* was not confirmed. The X's represent sites examined in which no waterhyacinth were found. The contour lines represent the distributional limits of the insect population for various dates

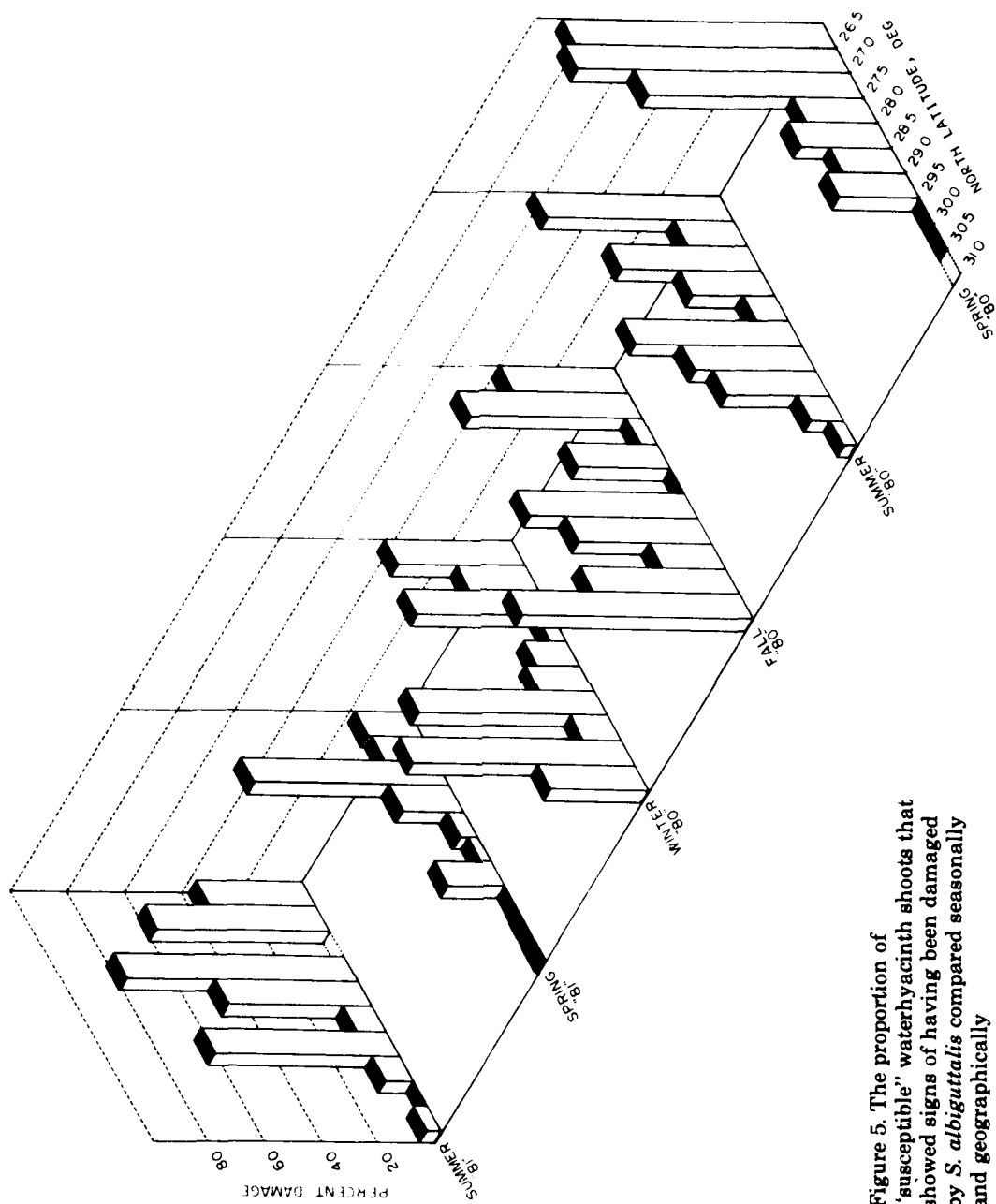


Figure 5. The proportion of "susceptible" waterhyacinth shoots that showed signs of having been damaged by *S. albiguttalis* compared seasonally and geographically

The type of plant sampled, therefore, varied considerably (see Figure 6) and consisted of the plants considered most likely to be infested among those available at each site. These usually were plants growing along the fringes of a stand. A multivariate analysis of variance was performed on the plant measurements to determine if the plant type varied significantly. Wilks' criterion showed a significant area by quarter interaction in a simultaneous test of significance over all plant measurements (see Table 1). Since the multivariate interaction was significant, the results of univariate analyses were inconsequential and plant type was not uniform.

A discriminant analysis was performed to analyze the pattern of dispersion of the various plant types among the sites. The results of this analysis are summarized in Table 2 and Figure 7. Site discrimination required only five of the

Table 1  
Results of Univariate and Multivariate Analysis of Variance.  
The Numbers are F-Values and all are Significant at  $P > 0.01$   
Unless Otherwise Indicated

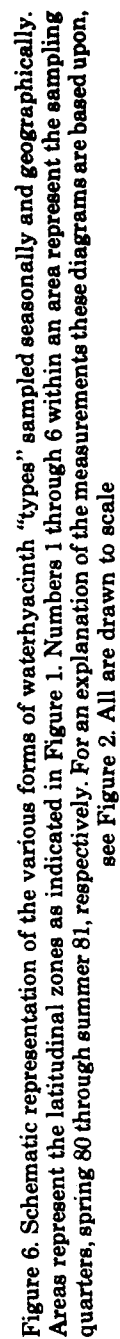
Variable	Effects			
	Area	Quarter	Area $\times$ Quarter	Overall
Root length	7.34	21.27	5.76	7.37
Leaf length	8.57	60.97	5.75	11.04
Petiole length	8.64	49.22	5.12	9.54
Petiole width	9.02	40.58	4.32	8.24
Lamina length	8.40	86.08	6.04	13.44
Lamina width	10.97	35.58	6.26	9.48
Petiole ratio	3.16	51.32	5.46	9.12
Leaf ratio	3.37	29.03	2.53	4.99
Lamina ratio	3.03	79.26	2.70	9.46
Root to leaf	8.11	6.51	4.03	4.89
Multiple	1.30*	4.53	3.36	-

\* Prob.  $> F = 0.06$ .

Table 2  
Standardized Coefficients of the Canonical Variables  
Formed in the Discriminant Analysis in which Plant Measurements  
(Converted to log 10) Were Used as Criteria for Discrimination Among Sites

Variable	Standard Deviation	CVI	CVII	CVIII	CVIV	CVV
Root length	0.18	0.29	0.25	0.18	0.93	-0.10
Leaf length	0.12	0.08	-0.66	-1.71	0.48	-0.43
Petiole width	0.09	-0.49	0.55	-0.32	-0.04	-0.73
Lamina length	0.10	0.65	1.09	1.19	-0.97	1.07
Lamina L:W	0.06	0.22	-0.48	0.15	0.08	-1.15
Cumulative proportion of total dispersion	-	0.52	0.72	0.85	0.94	1.00

NOTE: Coefficients were standardized by multiplication with the standard deviations of the original variables.



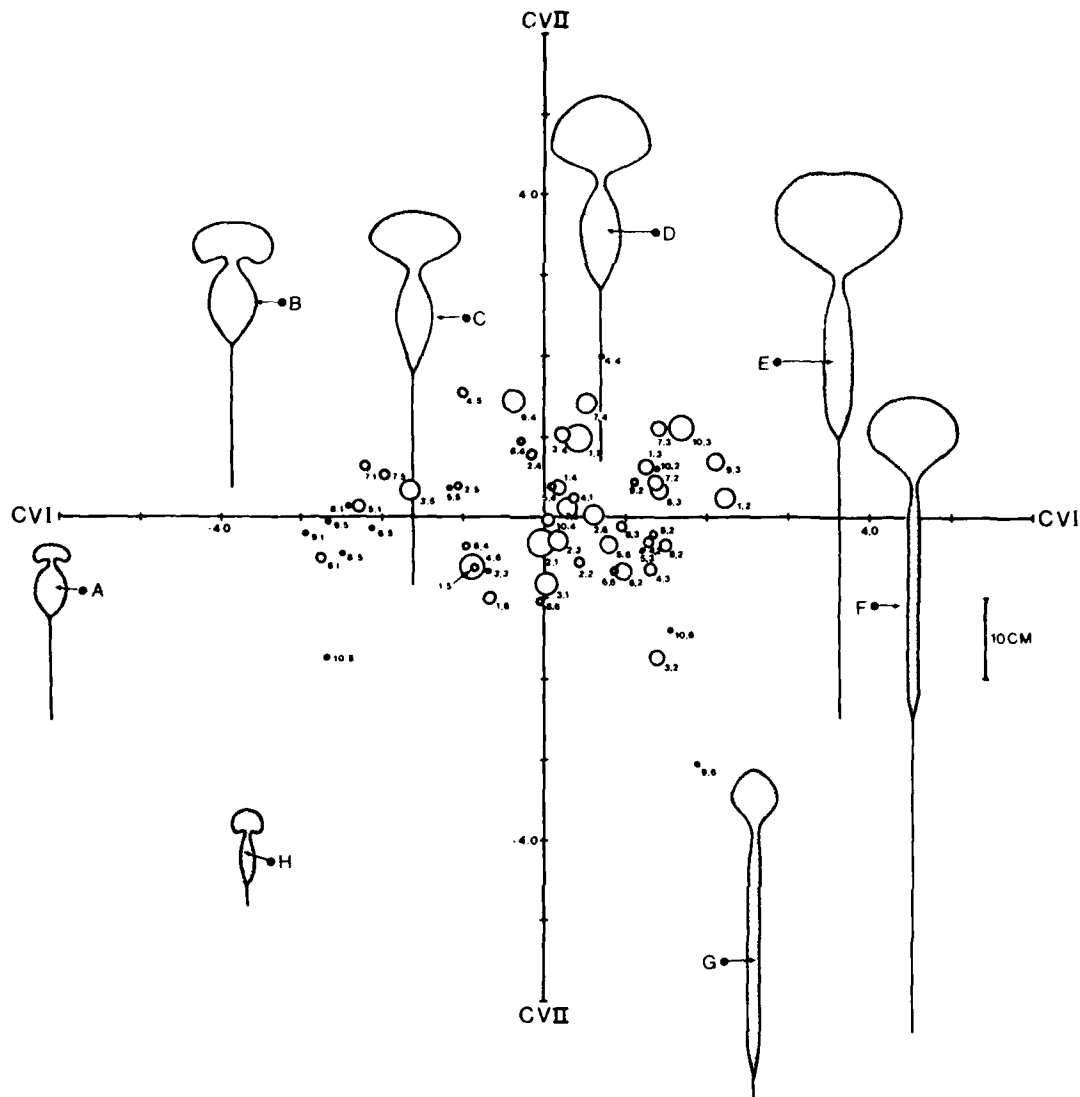


Figure 7. Results of the discriminant analyses in which plant measurements were used to classify the plants as to site. The circles are the centroids representing the means for each site and are proportional in size to the population intensity of *S. alboguttalis* for each site. The numbers by each circle represent the area and quarter for the site (e.g., 5,6 indicates Area 5, Quarter 6 or ca. 28°N, summer 1981). The diagrams indicated by points A-H represent examples of plants at various points on this ordination

original variables and the first two canonical variables (CV's) accounted for 72 percent of the total dispersion (Table 2). The mean values of the first two canonical variates for each site are plotted in Figure 7. As the schematic illustrations of the plants show, those with large laminae are positioned towards the positive side of the scale on CVI, whereas those with wide petioles are positioned towards the negative in this ordination. Those plants with wide petioles and large laminae are

at the positive end of the scale on CV II, whereas those with long leaves and petioles and a lanceolate leaf shape (a high lamina length to width ratio) are towards the negative end. Sites at which the plants were heavily infested by *S. albiguttalis* tend towards the origin and the upper right quadrant in the ordination.

The results of these first analyses indicated that the plant type sampled was not uniform, that sites could be discriminated based upon the plant types present, and a possible relationship between plant type and *S. albiguttalis* infestation levels existed.

Factor analysis was conducted as a means of combining correlated plant measurements into sets of fewer variables and thereby reducing the dimensionality of the "plant type" characterization. This effectively reduced the original 10 variables to 4 factors that accounted for 97.8 percent of the total variance (Table 3). The first factor was comprised of high loading coefficients for lamina width, lamina length, leaf length, petiole length, the ratio of lamina length to width, root length, and the ratio of lamina length to width, in this respective order. All of these coefficients were positive; hence, high values for any of these variables would tend to increase the score for Factor 1 in a positive direction. The factor may be interpreted as an index of plant size since all of the included variables would have large values for large plants and small values for small plants. The plants in Area 1 during Quarter 2 had the highest positive value for Factor 1 while those at Area 10 during Quarter 5 had the highest negative values. A comparison of the schematics of those plants in Figure 6 helps in the interpretation of the meaning of Factor 1.

The only two variables that loaded heavily on Factor 2 were root length and the ratio of root length to leaf length. Again, the coefficients were both positive. This factor can be interpreted as indicative of the extent of development of the root system, especially relative to the shoot. Plants with long roots and short leaves

Table 3  
Rotated Factor Pattern Showing the Loading  
Of Each Original Variable on Each Factor Score.  
Any Value of 0.4 or Less Was Considered Zero Loading

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Root length	0.627	0.749	0.071	0.100
Leaf length	0.881	-0.046	0.208	0.348
Petiole length	0.823	-0.061	0.216	0.473
Petiole width	0.006	0.035	-0.984	-0.137
Lamina length	0.945	0.001	0.161	0.031
Lamina width	0.983	0.027	-0.153	0.051
Petiole ratio	0.643	-0.074	0.594	0.427
Leaf ratio	-0.166	0.154	-0.153	-0.962
Lamina ratio	0.575	-0.042	0.490	0.013
Root to shoot	-0.232	0.928	-0.101	-0.250
Cumulative % variation	58.8	77.3	89.6	97.8

would tend to have high positive values, whereas those with short roots and long leaves would tend towards negative values. Site 5,2 (Area 5, Quarter 2) had the highest positive score and site 10,5 again had the highest negative score. Compare these in Figure 6.

Factor 3 was primarily indicative of leaf shape. Plants with spindly petioles and lanceolate laminae had high positive scores whereas those with robust, thick petioles and more uniform laminae had high negative scores. Compare site 3,2 and site 7,1 for the extremes on Factor 3.

Factor 4 again contrasted long, thin, spindly petioles (high positive) with short, fat, robust ones (high negative) but additionally considered the length of the lamina relative to the total leaf length. Hence, plants with short leaves but proportionally long laminae would also tend towards the negative end of the scale. Thus, the factor probably is indicative of leaf size since only very short leaves would have high lamina length to petiole length ratios. Also, only large leaves would have high petiole length to diameter ratios. The extremes on this factor were site 9,6 (positive) and site 8,4 (negative).

Factor analysis proved to be an excellent approach for defining plant type in a quantitative manner. The factors created were, by definition, orthogonal and, by using these as variables for plant type variables, intercorrelations were eliminated. Partial correlation analyses were then conducted to determine if either area or quarter were correlated with percentage infestation after the linear effects of plant type were removed. Area was considered a continuous variable with values of one to ten and the partial correlation of area with percentage infestation was only -0.316. Quarter was considered a continuous variable with values from one to six, and the partial correlation with percentage infestation was only -0.084. Hence, either the area at which and the date during which the samples were taken had no bearing upon the percentage of the plants infested or these relationships were not linear. Since the latter was suspected, the data were further analyzed using a multiple regression procedure.

Samples were collected during the course of this study over more than a year. If the insect populations underwent an annual cycle, then one would expect that the percentage infestation would vary over the time period in a curvilinear fashion. Also, since the climates of north Florida and south Florida were radically different, one would expect that the pattern of variation in this annual cycle would be different from north to south. Hence, a time by latitude interaction should be anticipated. Assuming that at least a second-order polynomial would be needed to describe variation patterns, second-order terms were used in the analysis for both area and quarter, as well as the various interaction terms. Factor scores for each site were included as covariates to allow for the effect of plant type. Hence, the model tested was  $PCI = A + AQ + A^2 + Q^2 + A^2Q + AQ^2 + A^2Q^2 + \text{Factor 1} + \text{Factor 2} + \text{Factor 3} + \text{Factor 4}$ , where A = latitudinal area, Q = time as quarters, and PCI = percentage infestation. Factor 1 to Factor 4 were the factor scores for plant type for each site. When all possible regressions were tested, the model which explained the greatest variance with the fewest variables included A, Q, AQ, Q<sup>2</sup>,

AQ<sup>2</sup>, Factor 1, and Factor 4 and accounted for 52 percent of the total variation. A further analysis of this model is presented in Table 4.

Although this model was significant, 48 percent of the variance was not explained. There are, of course, many other models that may be more efficient. These may include plant type by area or by quarter interactions or higher order polynomial equations. Much of the variation may simply be random and not accountable with the parameters examined.

By setting the values for plant type equal to the overall averages in the regression equation, one may examine the effects of area and quarter by calculating predicted values for each site. Figure 8 shows the predicted output of the regression equation adjusted to equal plant types. The resultant pattern shows definite seasonal

**Table 4**  
**Regression Analysis Explaining the Variation in the Percentage**  
**of Waterhyacinth Plants Damaged by *S. albiguttalis***  
**as a Function of the Geographic Location (Area),**  
**the Date (Quarter), and the Type of Plants Present**

<b>ANOVA:</b>							
<i>Source</i>	<i>DF</i>	<i>Sum of Squares</i>	<i>Mean Square</i>	<i>F-Value</i>	<i>Pr&gt;F</i>	<i>R<sup>2</sup></i>	<i>C.V.</i>
Model	7	21452	3064	7.74	0.0001	0.52	59%
Error	50	19809	396				
Corr. Total	57	41260					
				<u><i>STD. DEV.</i></u>	<u><i>MEAN</i></u>		
				19.9	33.5		
<i>Source</i>	<i>DF</i>	<i>Type I SS</i>	<i>F-Value</i>	<i>Pr&gt;F</i>	<i>Type IV SS</i>	<i>F-Value</i>	<i>Pr&gt;F</i>
Area (A)	1	4524	11.42	0.0014	7559	19.08	0.0001
Quarter (Q)	1	743	1.88	0.1769	8958	22.61	0.0001
A*Q	1	504	1.27	0.2647	6475	16.35	0.0002
Q <sup>2</sup>	1	63	0.16	0.6925	8618	21.75	0.0001
A*Q <sup>2</sup>	1	9519	24.03	0.0001	6212	15.68	0.0002
Factor 1	1	6081	15.35	0.0003	6028	15.22	0.0003
Factor 4	1	17	0.04	0.8354	17	0.04	0.8354
<b>REGRESSION:</b>							
<i>T for Ho:</i>							
<i>Parameter</i>	<i>Estimate (B)</i>	<i>Parameter = 0</i>	<i>Pr&gt;T</i>				
Intercept	162.3	6.32	0.0001				
Area	-20.5	4.37	0.0001				
Quarter	-78.9	4.76	0.0001				
A*Q	12.0	4.04	0.0002				
Q <sup>2</sup>	10.8	4.66	0.0001				
A*Q <sup>2</sup>	-1.6	3.96	0.0002				
Factor 1	11.6	3.90	0.0003				
Factor 4	-0.8	0.21	0.8354				

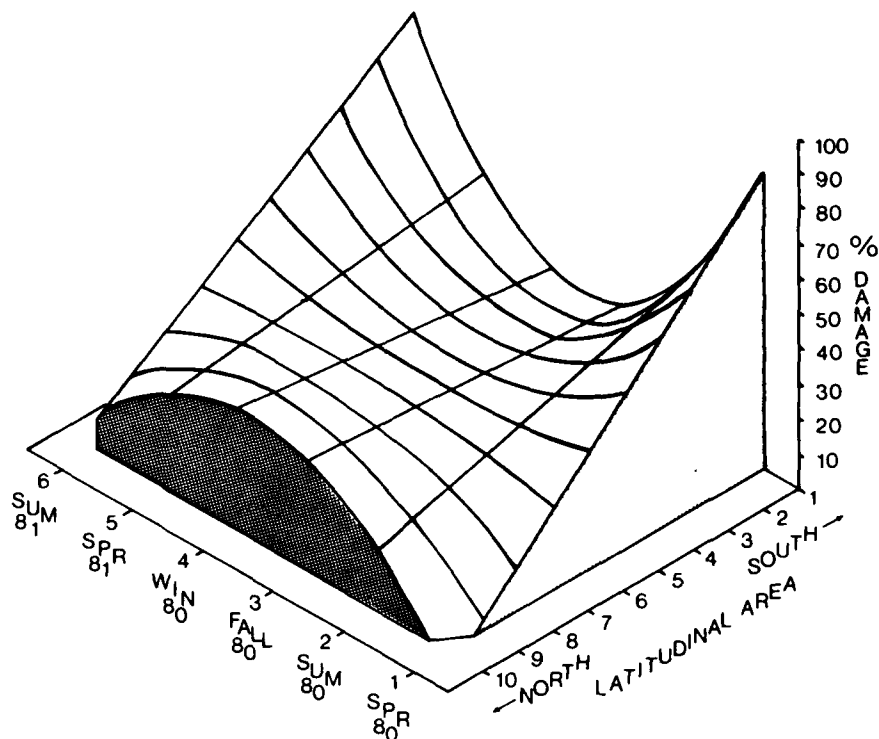


Figure 8. A three-dimensional illustration of a regression model showing the pattern of *S. albiguttalis* population intensities as influenced by latitude and season

patterns in both north and south Florida, but a lack of seasonality in the central areas. Interestingly, the pattern seems to reverse from north to south with high values in the spring and summer and low values in the fall and winter in the south. In the north, the high values tend to be in fall and winter and the low values in the spring and summer.

## DISCUSSION

This study was designed to determine if an operational release program would be necessary to disseminate *S. albiguttalis* throughout the range of waterhyacinth after the initial establishment of field populations was accomplished. If the original releases resulted in very localized population centers that were concentrated at the release sites, and if dispersal away from these areas was slow, then an operational program would probably be necessary. This would also be true if extirpation of the populations were frequent and recolonizations failed to occur. An operational program for the purpose of establishing populations of insects in new areas or recolonizing areas at which populations were lost would be difficult and expensive. Massive rearing or collecting efforts would be required in order to obtain adequate numbers of insects for this purpose.

The results of the dispersal surveys described herein clearly show that *S. albiguttalis* dispersed readily and rapidly after several populations were established. In fact, in the 550 days following 1 Jan 1979, the range of this insect expanded northward at least 528 km, an average of slightly less than 1 km/day. This expansion did not occur at a constant rate, of course, but rather tended to exponentiate during the first 8 months of 1979 then decrease during the fall and winter, and increase rapidly again during the spring and summer of 1980. The most rapid dispersal rates occurred during July and August of 1979 when the range increased northward by ca. 105 km within 1 month at a rate of ca. 4 km/day. It is apparent, then, that it is not necessary to invest the required time and effort in an extensive operational release program to disseminate populations of *S. albiguttalis* over a large geographical range. Instead, it is more appropriate to concentrate the release of the insects in a fairly restricted region to ensure that viable populations become established. This is to say that the evidence indicates that the insects themselves can saturate their resource and distribute themselves throughout the range of the waterhyacinth without human assistance. This is not a generalization, however, in that the same cannot be said for all species of insects that one might work with but it does seem to be so in the case of *S. albiguttalis*.

The quantitative aspects of this project have provided a great deal of insight into the patterns of resource utilization by *S. albiguttalis*. It is apparent that population intensities vary tremendously both spatially and temporally. It is also clear that waterhyacinth may be considered a coarse-grained resource with regard to the pattern of utilization by *S. albiguttalis*. The insect does not appear to perceive all morphotypes or growth forms of the plant as alike, but rather discriminates among them in some manner and utilizes them differently. Hence, no amount of effort will establish populations of this insect on plants that the insect perceives as unsuitable. Our problem is to define the dimensions upon which this perception is based. This discrimination for plant type was evident by a tendency towards higher infestation intensities on the more robust plants even amongst plants which all appeared to be suitable to *S. albiguttalis*.

When the effects of plant type were removed in order to ascertain more clearly seasonal and latitudinal variations in infestation intensities, it was determined that seasonal variation was curvilinear whereas latitudinal variation was linear and latitude affected the characteristics of the seasonal curve. In the south, populations were high during the hottest part of the year and lower during the cooler months. The reverse was true in the north. This pattern is difficult to explain without a great deal of speculation and should be the subject of further research. The specific purpose of this study was not so much to determine seasonal patterns of insect abundance as to determine if populations persisted at different latitudes throughout the year. With this in mind, it has been concluded that the *S. albiguttalis* populations can and do survive throughout all areas of Florida over the entire year. This is even true for those populations in the north which are sometimes exposed to extremely cold winter conditions. Although the populations appear to be low in the north during the spring, it is felt that this is due to the

resurgence of the waterhyacinth populations and a rapid increase in the number of plants. The insect populations do not numerically respond with equal rapidity, so a temporary dilution of the relative intensity results. Because these populations do persist, it should be concluded that there is no need for annual restocking of these areas. In fact, it appears that there is no need for further releases of *S. albiguttalis* in Florida.

## REFERENCES

- Andres, L. A., and Bennett, F. D. 1975. "Biological Control of Aquatic Weeds, *Ann. Rev. Entomol.*, Vol 20, pp 31-46.
- Barr, A. J., et al. 1979. *SAS Users Guide*, SAS Institute, Inc., Raleigh, N.C.
- Bennett, F. D., and Zwolfer, H. 1968. "Exploration for Natural Enemies of the Waterhyacinth in Northern South America and Trinidad, *Hyacinth Contr. J.*, Vol 7, pp 44-52.
- Blackburn, R. D., Sutton, D. L., and Taylor, T. 1969. "Biological Control of Aquatic Weeds," *J. Irrig. and Drain. Div., Amer. Soc. Civil Eng.*, Vol 97, No. IR3, pp 421-432.
- Center, T. D., and Durden, W. C. 1981. "Release and Establishment of *Sameodes albiguttalis* for the Biological Control of Waterhyacinth," *Environ. Ent.*, Vol 10, No. 1, pp 75-80.
- Cordo, H. A., and DeLoach, C. J. 1978. "Host Specificity of *Sameodes albiguttalis* in Argentina, A Biological Control Agent for Waterhyacinth," *Environ. Entomol.*, Vol 7, No. 2, pp 322-328.
- DeLoach, C. J. 1976. "*Neochetina bruchi*, A Biological Control Agent of Waterhyacinth: Host Specificity in Argentina," *Ann. Entomol. Soc. Am.*, Vol 69, pp 635-42.
- DeLoach, C. J., and Cordo, H. A. 1976a. "Life Cycle and Biology of *Neochetina bruchi*, A Weevil Attacking Waterhyacinth in Argentina, With Notes on *N. eichhorniae*," *Ann. Entomol. Soc. Am.*, Vol 69, pp 643-52.
- DeLoach, C. J., and Cordo, H. A. 1976b. "Ecological Studies of *Neochetina bruchi*, and *N. eichhorniae* on Waterhyacinth in Argentina," *J. Aquatic Plant Manag.*, Vol 14, pp 53-9.
- DeLoach, C. J., and Cordo, H. A. 1978. "Life History and Ecology of the Moth *Sameodes albiguttalis*, A Candidate for Biological Control of Waterhyacinth," *Environ. Entomol.*, Vol 7, pp 309-321.
- DeLoach, C. J., et al. 1980. "*Acigona infusella*, A Potential Biological Control Agent for Waterhyacinth: Observations in Argentina (With Descriptions of Two New Species of *Apanteles* by L. DeSantis)," *Ann. Entomol. Soc. Am.*, Vol 73, pp 138-146.
- Dixon, W. J., and Brown M. B. (eds.). 1977. *BMDP-77. Biomedical Computer Programs P-Series*, Univ. Calif. Press, Berkely, Calif.
- Dougenik, J. A., and Sheehan, D. E. 1979. "SYMAP User's Reference Manual," Laboratory for Computer Graphics and Spatial Analysis, Graduate School of Design, Harvard Univ., Cambridge, Mass.

- Holm, L. 1969. "Weed Problems in Developing Countries," *Weed Sci.*, Vol 17, No. 1, pp 113-118.
- Holm, L. G., et al. 1977. *The World's Worst Weeds, Distribution and Biology*, University Press of Hawaii, Honolulu.
- Little, E. C. S. 1965. "The World Wide Distribution of the Waterhyacinth," *Hyacinth Control J.*, Vol 4, pp 30-32.
- Little, E. C. S. 1968. "The Control of Water Weeds," *Weed Res.*, Vol 8, pp 79-105.
- Manning, J. H. 1979. "The Establishment of Waterhyacinth Weevil Populations in Louisiana," *J. Aquat. Plant Manage.*, Vol 17, pp 39-41.
- Perkins, B. D. 1973. "Release in the United States of *Neochetina eichhorniae* (Warner), An Enemy of Waterhyacinth," *Proc. 26th Ann. Meet. S. Weed Sci. Soc.*, p 368 (Abstr.).
- Perkins, B. D. 1974. "Anthropods that Stress Waterhyacinth," *PANS*, Vol 30, No. 3, pp 304-314.
- Perkins, B. D., and Maddox D. M. 1976. "Host Specificity of *Neochetina bruchi* Hustache (Coleoptera:Curculionidae), A Biological Control Agent for Waterhyacinth," *J. Aquat. Plant Manage.*, Vol 14, pp 59-64.
- Silveira-Guido, A., and Perkins, B. D. 1975. "Biology and Host Specificity of *Cornops aquaticum* (Bruner) (Orthoptera:Acrididae), A Potential Biological Control Agent for Waterhyacinth," *Environ. Entomol.*, Vol 4, pp 400-404.
- Sinha, R. N. 1977. "Uses of Multivariate Methods in the Study of Stored-Grain Ecosystems," *Environ. Entomol.*, Vol 6, pp 185-192.
- Zeiger, C. F. 1979. "Operational Collection and Release of Waterhyacinth Weevils," *J. Aquat. Plant Manage.*, Vol 17, p 78.

# BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

## Overseas Searches for Insects for Control of Aquatic Plants

by  
Joseph K. Balciunas\*

### INTRODUCTION

Many exotic aquatic plant species have become established in aquatic ecosystems of the United States. Some, such as alligatorweed (*Alternanthera philoxeroides*), waterhyacinth (*Eichhornia crassipes*), Eurasian watermilfoil (*Myriophyllum spicatum*), and hydrilla (*Hydrilla verticillata*), have become serious weed problems, while some very recent introductions, such as hygrophila (*Hygrophila* prob. *polysperma*) are just beginning to show their pest potential.

Currently, the management of these and other aquatic weeds relies primarily on herbicides. However, the use of these chemicals is being increasingly restricted for environmental and other reasons, and their cost is becoming prohibitive for wide-scale application. Mechanical methods, while usually less risky environmentally, are so expensive that their use is usually limited to portions of high-priority waters. Accordingly, the use of natural enemies to control aquatic vegetation is receiving increased attention.

Classical biological control, i.e., the importation and establishment of a natural enemy (usually an insect) from the home range of the target pest, is a proven technique for controlling some terrestrial weeds with the control of kalamath weed in western United States and of prickly-pear in Australia being the most notable in a long list of successes. Imported insects have also controlled aquatic weeds with the control of alligatorweed by the beetle *Agasicles hydrophila* being the best example. Waterhyacinth is now also being partially controlled, at least in Louisiana, by imported weevils, *Nechetina* spp. The most recently released species, the moth *Sameodes albiguttalis*, is now also beginning to show control of this floating nuisance at some of the first release sites in Florida.

To date all the insects released to control aquatic weeds in the United States have been imported from South America to control alligatorweed and waterhyacinth, both natives of South America. These successful introductions were primarily the result of work performed at USDA's laboratory at Hurlingham, Argentina. Currently, the United States has no scientists overseas working on biological control of aquatic weeds. This is especially unfortunate in view of the long time periods necessary to discover, evaluate, import, and establish a new biological control agent. The three insect species imported for the control of waterhyacinth averaged approximately 10 years each from initial discovery to release in the United States.

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As a result of the lack of foreign exploration for natural enemies, there are now no exotic insects awaiting release for the other aquatic weeds in the United States. This includes the noxious weed hydrilla, which, since its introduction 20 years ago, has become established in almost all of the southern states and which is difficult and expensive to control by herbicides. While some overseas searches for possible biocontrol agents for hydrilla have been conducted, primarily PL 480 projects in India and Pakistan, no agents suitable for importation and release have been found. The natural enemies of hydrilla in its native range remain largely unknown.

In June 1980, the U.S. Department of Agriculture entered into a specific cooperative agreement with the University of Florida entitled "Foreign Search for Biological Agents to Control Aquatic Weeds." Most of the funds for this project would be provided by U.S. Army Corps of Engineers, Waterways Experiment Station (WES), Aquatic Plant Control Research Program. Initial emphasis would be on locating possible biological control agents for hydrilla. Initial searches would be focused in tropical Asia, which is considered by most experts to be the area of origin for hydrilla and which is an area where the insects associated with hydrilla are poorly known.

Replies to questionnaires sent to possible cooperators in Asia, along with advice from colleagues here in the United States, allowed plans to be made for an approximately 4-month trip, beginning in February 1981. The primary objectives of this first trip were to:

- a. Learn hydrilla's Asian distribution, recommended collecting areas, etc., during a 3- to 4-day visit with Dr. C. D. K. Cook in Zurich, Switzerland.
- b. Visit India, Burma, Thailand, Malaysia, and northern Australia for 1 to 2 weeks each, and meet with possible cooperators in each country who might be willing to assist in later, long-term surveys.
- c. Determine costs, travel and collecting restrictions, probable areas for collecting, and other information necessary for realistic planning of an extended survey in each country.
- d. Attempt to locate additional sources of funds and technical assistance for extended surveys in each country.
- e. If possible, collect hydrilla and its associated insects in each country.
- f. Learn of any biological agents in any of these countries which may be useful in controlling aquatic weeds other than hydrilla.
- g. Spend approximately 2 months on various islands of Indonesia. Repeat objectives b-f.
- h. If a probable biological control candidate is found in Indonesia, do sufficient host specificity and life history testing to allow organism to be imported into U.S. quarantine facilities for more complete testing.
- i. Bring back insects collected on hydrilla as well as voucher herbarium specimens.
- j. Identify organisms collected.

- k. Consult with experts concerning the feasibility of any of the species collected serving as a biological control agent.
- l. Use all information gained in making decision for probable destinations for subsequent trips.

## RESULTS

An unexpected delay in obtaining an Indonesian visa caused a sudden postponement of the trip for 3-1/2 months, with final departure occurring on 21 June 1981. A map of the main routes of the Asiatic portion of the trip is shown in Figure 1. Table 1 presents a list of the collection sites in Asia. This list does not include the many sites inspected that were not infested by hydrilla.

A preliminary list of the insects and other organisms collected in Asia is presented in Table 2. This list is extremely preliminary since the identifications are based on knowledge of the U.S. fauna. The more important groups, i.e., probable and possible natural enemies of hydrilla, are being identified by experts. The scanty and scattered taxonomic literature is also being assembled for aquatic insects of tropical Asia. A more detailed list of insect species will then be prepared.

The more important insects found in each country, along with other major observations, appear in the following section that lists the major accomplishments for each country.

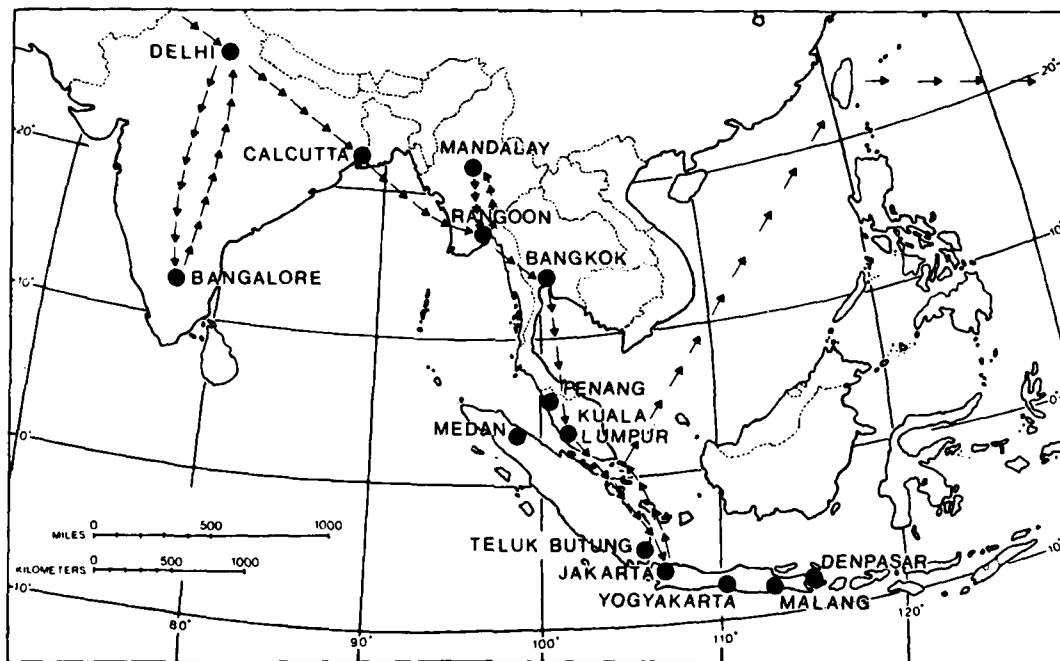


Figure 1. Map illustrating routes of major travels during initial trip to Asia in search of natural enemies of aquatic weeds (21 Jun - 23 Oct 1981)

Table 1  
Collection Sites in Asia

Collection No.	Host Plant	Date	Site	Location	State or City	Country
81KAR201	<i>Hydrilla verticillata</i>	01 JUL 81	Arkavarti Stream	12 km N Bangalore	Karnataka	India
81KAR202		01 JUL 81	Kulunanahalli Pond	30 km S of Tumkur		
81KAR203		01 JUL 81	Baragenahalli Pond	Baragenahalli Village		
81KAR204		03 JUL 81	Ummulugodu Pond	Ummulugodu Village		
81KAR205		03 JUL 81	Seshagirihalli Pond	Seshagirihalli Village		
81KAR206		03 JUL 81	Dasappadoddi Pond	Dasappadoddi Village		
81BUR201		10 JUL 81	Inya Lake	Washington Park	Rangoon	Burma
81BUR201	Alligatorweed	10 JUL 81	Inya Lake	Washington Park	Rangoon	Burma
81BUR202	<i>Hydrilla verticillata</i>	14 JUL 81	Mandalay Moat	Near SW corner of pond	Mandalay	Burma
81PEN201		31 JUL 81	Irrigation Ditch	Near Balik Pulau Village	Penang	Malaysia
81JAV201		11 AUG 81	Cibinong Pond	300 M Cibinong Village	West Java	Java
81JAV202		19 AUG 81	Curug Reservoir	North end of Reservoir	West Java	Java
81JAV203		27 AUG 81	Rawa Pening Reservoir	Near Village of Tuntang	Central Java	Java
81JAV204		28 AUG 81	Jombor Lake	10 km S of Klaten	Central Java	Java
81JAV205		01 SEP 81	Senggreng Lake	25 km S of Malang	East Java	Java
81JAV206		01 SEP 81	Kediri Canal	3 km N of Kediri	East Java	Java
81SUM201		07 SEP 81	Canal BBGK1	1 km from Lake Sappan	Lumpong Prov.	Sumatra
81SUM501	<i>Myriophyllum spicatum</i>	11 SEP 81	Lake Toba	E shore of Samosir Island	N Sumatra	Sumatra
81SUM202	<i>Hydrilla verticillata</i>	11 SEP 81	Lake Toba	E shore of Samosir Island		
81SUM801	<i>Potamogeton</i> sp.	12 SEP 81	Lake Toba	NE shore of Samosir Island		
81SUM502	<i>Myriophyllum spicatum</i>	12 SEP 81	Lake Toba	E shore of Samosir Island		
81SUM802	<i>Potamogeton</i> sp.	14 SEP 81	Lake Toba	SE end of Samosir Island		
81SUM203	<i>Hydrilla verticillata</i>	14 SEP 81	Lake Toba	SE shore of Samosir Island		
81SUM204	<i>Hydrilla verticillata</i>	15 SEP 81	Kutabaru Canal	Kutabaru Village		
81SUM205	<i>Hydrilla verticillata</i>	16 SEP 81	Tanjung Kililing Pond	50 km SW of Medan		

**Table 2**  
**Preliminary List of Insects and Other Macroinvertebrates**  
**Collected on Hydrilla in Asia (21 June-23 October 1981)**

<i>Name</i>	<i>Country</i>	<i>No. of Specimens</i>	<i>Collection Numbers</i>
Suborder Anisoptera (unid.)	Sumatra	1	Sum81205
	Java	1	Jav81201
Gomphidae	Java	1	Jav81205
Libellulidae	Java	3	Jav81201, Jav81202, Jav81204
	Sumatra	2	Sum81204
	India	2	Kar81202, Kar81206
	Malaysia	1	Pen81201
		11	
Suborder Zygoptera (unid.)	Sumatra	1	Sum81204
Coenagruidae (unid.)	Java	3	Jav81201, Jav81204
<i>Pseudagrion rubriceps</i>	Java	7	Jav81201, Jav81203, Jav81205
	Sumatra	15	Sum81204
		26	
Order Ephemeroptera	India	2	Kar81205, Kar81206
Neophemeridae	Malaysia	1	Pen81201
Caenidae	Java	2	Jav81203
		5	
Order Hemiptera			
Nepidae			
<i>Ranatra</i> sp.	Java	2	Jav81204
<i>Nepa</i> sp.	Sumatra	1	Sum81204
		3	
Order Trichoptera (unid.)	Java	1	Jav81201
Brachycentridae	Sumatra	3	Sum81205
	India	1	Kar81202
		5	
Order Lepidoptera			
Pyalidae			
<i>Paraponyx</i> sp.	India	17	Kar81201, Kar81204, Kar81205
	Sumatra	3	Sum81201, Sum81204, Sum81205
	Java	28	Jav81201, Jav81203.H, Jav81204, Jav81205, Jav81206
		5	
Order Lepidoptera			
Pyalidae	India	5	Kar81201, Kar81203, Kar81205
		53	
Order Coleoptera			
Chrysomelidae	Burma	10	Bur81801
Hydrophilidae	India	3	Kar81202, Kar81206
Curculionidae	India	6	Kar81205, Kar81206
Elmidae	Sumatra	3	Sum81205
Dytiscidae	Java	1	Jav81201
		23	

(Continued)

Table 2 (Concluded)

<i>Name</i>	<i>Country</i>	<i>No. of Specimens</i>	<i>Collection Numbers</i>
Order Diptera			
Stratiomyidae	Java	1	Jav81204
Chironomidae	India	3	Kar81203
	Sumatra	9	Sum81201, Sum81801
	Java	163	Jav81201, Jav81204, Jav81205
		176	
Order Decapoda (unid.)	Java	1	Jav81202
Shrimp			
Palaemonidae	India	1	Kar81203
	Sumatra	13	Sum81201, Sum81204
	Java	3	Jav81202, Jav81203
		18	
Order Decapoda			
Clams	Sumatra	10	Sum81201, Sum81202, Sum81205
Order Gastropoda			
Hydrobiidae	Burma	1	Bur81201
	Java	12	Jav81201, Jav81203
	India	20	Kar81201, Kar81203, Kar81204, Kar81205, Kar81206
	Sumatra	30	Sum81201, Sum81202, Sum81203, Sum81204, Sum81205, Sum81502
		63	
Order Gastropoda			
Planorbidae	Java	91	Jav81201, Jav81204, Jav81206
	India	21	Kar81201, Kar81202, Kar81205
	Sumatra	1	Sum81204
	Burma	35	Bur81201, Bur81202
		148	
Physidae	India	4	Kar81201, Kar81205
	Java	1	Jav81201
	Sumatra	3	Sum81205
		8	
Lymnaeidae	India	1	Kar81203
	Sumatra	1	Sum81204
	Java	17	Jav81202, Jav81203.H, Jav81205
		19	
Order Tricladida			
Planariidae	Sumatra	4	Sum81501

## MAJOR ACCOMPLISHMENTS

### Switzerland (22-25 June)

Distribution, morphology, ecology, and habitats of hydrilla in Asia were discussed with Dr. C. D. K. Cook, Director, Zurich Botanical Gardens.

### India (26 June-1 July)

Use of PL 480 monies for searches for insect enemies of hydrilla in India was discussed with Dr. Stanley Stone, Director, Ferro, USDA. While he would like to see such a project initiated, the Indian government has approved very few PL 480 projects in the last 5 years. Dr. Sankaran, head of the CIBC Indian station, agrees that there is little chance for approval of new PL 480 projects. However, he suggests that CIBC could collect and test hydrilla insects and bill the U.S. Embassy in Delhi, who could then pay CIBC with PL 480 monies. He is currently being reimbursed in this manner for scale insects CIBC is collecting for U.S. researchers.

Hydrilla was common in south-central India and several species of insects damaging this plant were collected. Moth larvae, similar to *Parapoynx diminutalis* (see Figure 2), were found at many locations and several specimens of another nymphuline species were also collected. Several species of small aquatic weevils, belonging to the genus *Bagous* (Figure 3), appeared to feed externally on hydrilla, while weevil larvae (Figure 4), probably also *Bagous* sp., were found boring inside hydrilla stems. Since Nearctic species of this genus are very host specific and since they reproduce quickly, these weevils will be tested further on the next trip to India. If they still show host specificity to hydrilla, we will then try to import them to quarantine facilities in the United States for further testing and possible release.

### Burma (9-16 July)

Members of the U.S. Embassy provided names of scientists and officials who might provide assistance. The in-country expenses for future trips, if done on an official passport, could probably be paid with PL 480 monies. Alligatorweed, extensively damaged by feeding of the larvae and adults of a tortoise beetle (Coleoptera:Chrysomelidae) (Figures 5 and 6), was observed in the Rangoon vicinity. Collections of insects (on hydrilla from Rangoon and Mandalay areas) did not include any species which damage the plant. Since collecting was done during the middle of the monsoon season, hydrilla was hard to locate and aquatic insect densities were probably lower than at other times.

### Thailand (16-23 July)

Aquatic weed infestations were inspected in central Thailand with Dr. Banpot Napompeth, Director, National Biological Control Research Center (NBCRC), and staff. They provided data on a moth, *Episamma pectinicornis*, that feeds on waterlettuce (*Pistia stratiotes*) and is as effective as herbicides in eradicating *Pistia* infestations. Since this moth is very specific (does not reproduce on any of the 100 plant species tested) it should seriously be considered for use on *Pistia* infestations in the United States and Panama. The most serious aquatic weed in

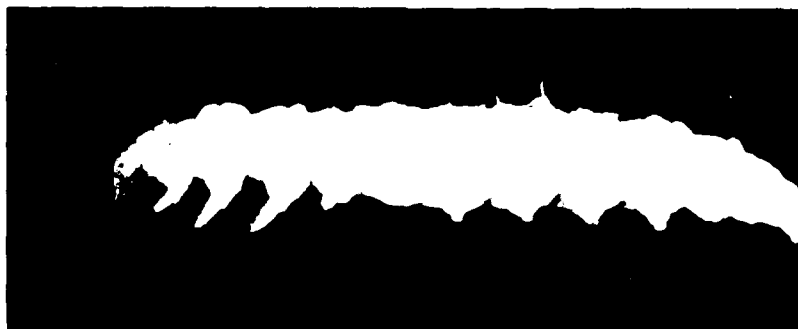


Figure 2. Caterpillar (*Parapoynx* sp.) found feeding on hydrilla growing in a pool of a stream near Bangalore in south-central India. A similar caterpillar was also found feeding on hydrilla growing in Sumatra and Java. This caterpillar closely resembles the hydrilla-damaging *Parapoynx diminutalis*, an Asiatic species recently established in Florida



Figure 3. Adult of *Bagous* species A. Several species of these small aquatic weevils were collected and appeared to be feeding on hydrilla growing in ponds in Karnataka state in south-central India. Since the New World *Bagous* are usually very host specific and have short developmental times (about 2 weeks from egg to adult), these weevils will be studied in greater detail during a future trip to India, to allow importation to U.S. quarantine facilities for testing required before release in the field

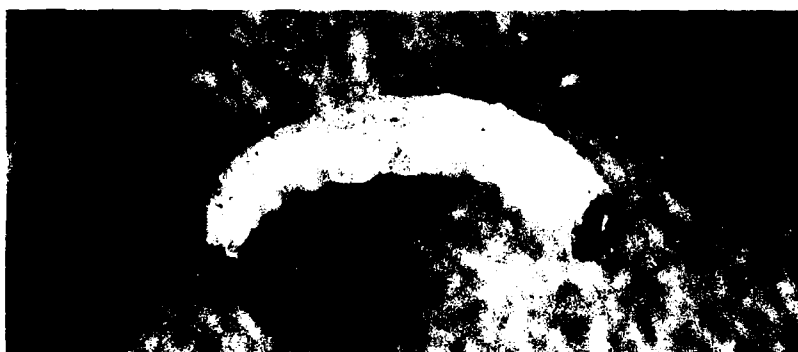


Figure 4. Weevil larvae, prob. a *Bagous* sp., found burrowing in hydrilla stems growing in a pond in south-central India



Figure 5. Leaves of alligatorweed, *Alternanthera philoxeroides*, from Lake Inya, Rangoon, Burma, showing feeding damage by a tortoise beetle (Coleoptera:Chrysomelidae). Three of these metallic, golden-green beetles are on the center of lowermost leaf in the photograph



Figure 6. Close-up of the larva of tortoise beetle (Coleoptera:Chrysomelidae) found feeding on alligatorweed growing at Lake Inya, Rangoon, Burma. Both the adults and larvae feed voraciously on alligatorweed

Thailand is *Mimosa pigra* (Figures 7 and 8), a recently introduced shrub that has quickly infested thousands of acres of aquatic and semiaquatic habitats. Luckily, this plant has not yet been introduced in the United States.

#### Malaysia (23 July-5 Aug)

Eventually, with the help of the staff at the U.S. Embassy in Kuala Lumpur, Malaysian scientists familiar with hydrilla were contacted. Hydrilla insects at Penang Island were collected. Dr. Ivor Caunter, Malaysia University of Science, agreed to initiate a cooperative project whereby a technician would collect insects on hydrilla and ship the specimens to the United States. Inspection of aquatic habitats during a long drive across the Malay peninsula did not provide any additional hydrilla infestations.

#### Indonesia (5 Aug-21 Oct)

Hydrilla appeared to be a problem mainly in newly formed reservoirs. A pyralid moth, similar to *Parapoynx diminutalis*, was found feeding on hydrilla at many of the sites. Eggs of a waterscorpion (Hemiptera:Nepidae) were frequently oviposited in hydrilla stems (see Figure 9) at one site in central Java, but this probably had a minor effect on the plant.

Several weeks were then spent collecting on the island of Sumatra (Figure 10). Moth larvae, similar to *Parapoynx diminutalis*, were again found damaging hydrilla at most sites. At Lake Toba, a large, deep, volcanic lake in North Sumatra, aquatic insect densities on submersed plants were very low. However, all hydrilla examined here was heavily grazed, probably by a fish, resulting in an unusual stunted, prostrate appearance (see Figure 11).



Figure 7. *Mimosa pigra* infestation in a shallow lake near Saraburi in central Thailand. This shrub is a recent introduction in Thailand and has now become the number one aquatic nuisance in that country. This plant has not yet been introduced into the United States



Figure 8. Flowers and fruit of *Mimosa pigra*



Figure 9. Egg of a waterscorpion (Hemiptera:Nepidae) inserted into hydrilla stem growing in central Java. While this oviposition site may cause easier fragmentation of the hydrilla stem or serve as an entrance point for a pathogen, the hydrilla is otherwise unharmed by waterscorpions since they are predators on a wide variety of aquatic fauna

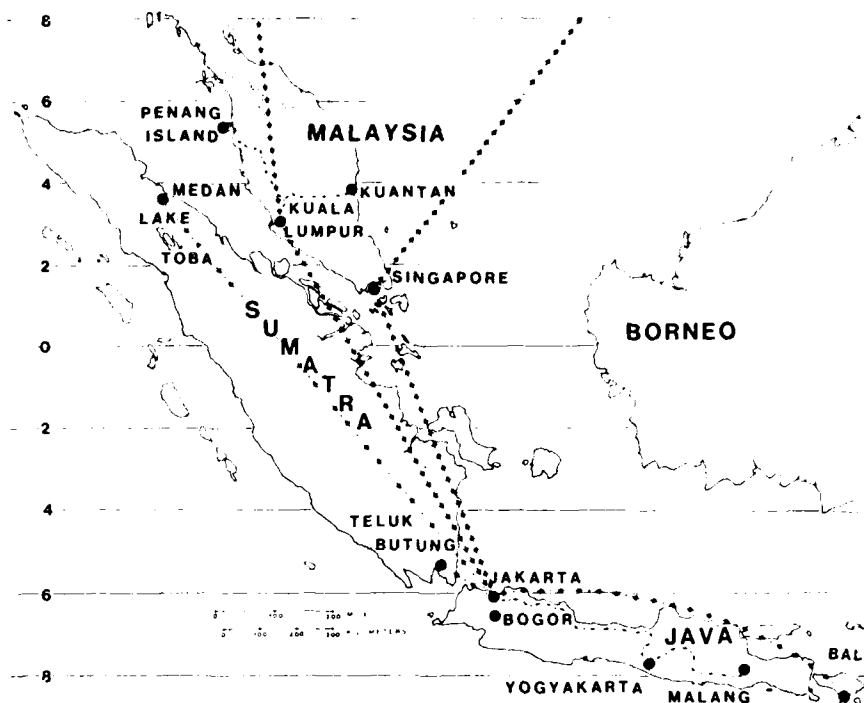


Figure 10. Map depicting travels in peninsular Malaysia, and the Indonesian Islands of Java, Sumatra, and Bali in search of natural enemies of aquatic weeds



Figure 11. Hydrilla, *Hydrilla verticillata* (right); Eurasian watermilfoil, *Myriophyllum spicatum* (center); and a pondweed, *Potamogeton* sp. (left), collected from the same vicinity of Lake Toba, north Sumatra. Note the short, stunted appearance of the hydrilla. This specimen was among the largest found. All specimens of hydrilla exhibited severe grazing of the apical portions (probably by a fish) resulting in short, prostrate plants that usually could only be located by diving

## SUMMARY

This initial trip to Asia was very successful. Since the potential area to be explored for natural enemies was enormous, and since I had never been in Asia and did not know what difficulties to expect, some of the primary aims of this trip were to learn the distribution of hydrilla in various parts of Asia, to discover the difficulties in collecting and testing insects associated with hydrilla, and to become acquainted with scientists living in these countries who might be able to offer assistance on future trips. All these goals were achieved. Hydrilla was observed in all countries visited and firsthand knowledge was gained of requirements and difficulties for collecting and testing in the country. Scientists who would be willing to lend assistance were located in each country. In Burma, however, the amount of assistance that can be provided by Burmese scientists is severely restricted by the Burmese government. In Malaysia, a cooperative project to search for hydrilla insects was initiated with Dr. Ivor Caunter at Malaysia's University of Science.

Progress was also made in the overall project goal of locating possible biological control agents for hydrilla. Several species of a small aquatic weevil belonging to the genus *Bagous* were collected feeding on hydrilla in south-central India that appeared to be very promising natural enemies. Dr. Charlie Obrien of Florida A&M University, who is the world authority on this genus, says that most *Bagous* are extremely host specific, have short generation times (around 2 weeks), are attracted to black-lights, and all immature life stages are usually confined on or in the plant host. These are ideal characteristics for a potential biocontrol agent. During my next trip to Asia, I plan to test the *Bagous* weevils in India to see if they are, in fact, host specific. If they are sufficiently host specific, I will ship living specimens to quarantine facilities in Gainesville, Fla., for more complete testing. Since weevils are frequently very destructive to their plant hosts, and with the weevil *Neochetina* spp. now demonstrating control of waterhyacinth at some locations in the United States, we are encouraged by the discovery of these natural enemies of hydrilla.

Potential biological control agents for other aquatic weeds were also noted during this trip. Much research has been done in Thailand with the moth *Episammia pectinicornis*, which is very destructive to water lettuce, *Pistia stratiotes*, and which appears to be very specific to this floating aquaphyte. Since waterlettuce is a major problem in the Panama Canal and is ranked as the third most noxious aquatic weed in Florida, and since it is a major aquatic pest in other southern states, we believe that this insect should be seriously considered for importation and release in the United States. We have now begun to assemble information to support our application to import this insect into quarantine for further testing. Once received into quarantine, this insect may receive clearance for release relatively rapidly (1 to 2 years) in view of the extensive prior testing conducted in Thailand.

This trip was noteworthy not only because of these accomplishments, but also because there were several general indications that natural control agents exist in Asia: (1) hydrilla usually becomes a problem only in recently formed (within the last 20 years) reservoirs; (2) on the relatively few occasions where hydrilla was known to have been established for a long time, it was usually not the dominant macrophyte and was being outcompeted by native vegetation such as coontail, or by more recently introduced plants such as waterhyacinth and *Salvinia molesta*. Thus, while hydrilla may have been abundant in some, usually newly formed, aquatic systems, where populations of its natural enemies may not have yet become established, in general, it appeared to be less abundant and competitive than in Florida. In view of the tremendous expenditures currently required for partial, temporary control, it would appear highly advisable to more thoroughly investigate the natural enemies of hydrilla in these areas, in case some of them may prove useful in controlling this nuisance in the United States.

# BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

## Lytic Enzyme Producing Microorganisms for Eurasian Watermilfoil Control

by  
Haim B. Gunner\*

### BACKGROUND

The rationale for the work reported in the following is the presence of tightly bound microfloral populations (apparently species determined) on Eurasian watermilfoil (*Myriophyllum spicatum* L). Since these microorganisms eventually form the bulk of the populations active in the decomposition of the milfoil, it was postulated that the most active of these could be screened for specific lytic enzyme activity and by nutritional induction the enzyme yield could be enhanced to the point where the organism could act temporarily as a pathogen rather than as a saprophyte. The advantage to such an approach is that the active organism derives from the ecosystem itself and thus escapes the discriminatory pressures active against an introduced species. Further, the pathogenicity induced is specific to the plant from which the organism is originally isolated and is temporary in nature, subsiding with the diminution of available substrates. Two target and plant tissues readily available to microbial attack, cellulose and pectin, were selected as substrates for which microbial populations could be readily identified. The potential of this approach has now been confirmed by the successful isolation and enhancement of lytic enzyme production by a cellulase-producing fungus, *Mycleptodiscus terrestris*, and a pectinase-producing actinomycete, Strain Br-2, both effective in the control of *M. spicatum*.

### RESULTS

Screening for cellulase activity is achieved by plating microorganisms on a medium in which cellulose is the sole source of carbon. The successful candidate organisms such as *M. terrestris* rapidly hydrolyze the cellulose and leave a clear zone. The organism is subsequently cultured in liquid medium in which cellulose in the form milled filter paper serves as the sole source of carbon. After a sequence of weekly transfers, the cellulase titer is maximized and the organism in its liquid medium is applied to the milfoil as a cellulolytic agent.

A similar technique is employed for the isolation of pectinolytic microorganisms. Microorganisms isolated from *M. spicatum* are screened on plates in which pectin is the sole source of carbon. Those capable of hydrolyzing the pectin will demonstrate pitting of the agar surface. After serial transfer and enhanced

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induction of pectinolytic enzymes, the microorganism is capable of total hydrolysis and liquefaction of the solid medium. The fact that such isolates are not rare among the populations inhabiting *M. spicatum* is demonstrated in Table 1.

It may be readily seen that 70 to 100 percent of the *M. spicatum* plants decay within 3 weeks. In addition, however, two other points of interest emerge. The first is the relative specificity of the isolates to *M. spicatum*; these achieve only a 10 to 40 percent decay level when applied to *M. heterophyllum*. Second is the incitement to cellulolytic activity by the simple addition of increments of the sterile 1 percent cellulose medium to the test chambers. In this instance, 80 percent of the *M. spicatum* plants decay within 21 days and 40 percent of the *M. heterophyllum*. This could confirm the presence of a stable cellulolytic flora associated with these plants which might be induced to cellulolytic activity by the addition of appropriate amendments.

Table 1  
Acceleration of Decay of *Myriophyllum* spp. by  
Cellulolytic and Pectinolytic  
Microbial Isolates from *M. spicatum*

Treatment	Percent Necrotic Plants*					
	<i>M. spicatum</i>			<i>M. heterophyllum</i>		
	Day 7	Day 14	Day 21	Day 7	Day 14	Day 21
Control untreated	0	0	0	0	0	0
Control 1% cellulose medium	0	70	80	10	40	40
Br-3	10	40	70	20	20	20
Br-4	20	30	70	0	0	0
P-3	10	20	80	30	30	30
P-4	0	40	90	40	30	30
P-6	20	80	90	10	10	10
P-7	60	80	100	0	10	10
P-8	10	70	100	10	10	20
Y-2	10	80	90	10	10	10
Y-4	10	70	100	10	20	40
Y-5	20	80	90	20	10	10

\* Ten plants observed per treatment; percentages based on numerical scores of 1 = least decay and 10 = maximum decay.

The acceleration of necrosis by the cellulolytic *M. terrestris* is shown in the data in Table 2. There is little suggestion of a dose-response relationship in the inoculum concentration employed and the lowest inoculum of 0.5 ml achieved maximum decay. Again, the addition of cellulose medium by itself stimulated significant necrosis, in this instance with a clear dose-response relationship, maximum decay being achieved with the highest concentration of inoculum.

The acceleration of decay of *Myriophyllum* spp. induced by the pectinolytic isolate Br-2 is shown in the data in Table 3. Again, the addition of sterile cellulose or

**Table 2**  
Acceleration of Necrosis of *Myriophyllum* spp. by  
*Mycropleptodiscus terrestris* and by  
Cellulose Induction Growth Medium

Treatment	Inoculum size, ml	Percent Necrotic Plants*					
		<i>M. spicatum</i>			<i>M. heterophyllum</i>		
		Day 14	Day 21	Day 28	Day 14	Day 21	Day 28
Cellulose medium	0.5	0	0	25	0	0	0
	1.0	25	25	50	25	25	50
	2.0	25	50	75	25	25	50
<i>M. terrestris</i>	0.5	50	100	100	50	50	50
	1.0	50	75	75	25	25	25
	2.0	75	75	75	25	25	75

\* Ten plants observed per treatment; percentages based on numerical scores of 1 = least decay and 10 = maximum decay.

**Table 3**  
Acceleration of Decay of *Myriophyllum* spp. by  
Isolate Br-2, an Actinomycete  
Isolated from *M. spicatum*

Treatment	Percent Necrotic Plants*					
	<i>M. spicatum</i>			<i>M. heterophyllum</i>		
	Day 7	Day 10	Day 21	Day 7	Day 14	Day 21
Control untreated	0	0	0	0	0	0
Control 1% cellulose medium	0	10	10	0	0	0
Control 1% pectin medium	10	40	50	20	30	40
Br-2 grown on cellulose medium	0	50	80	0	0	0
Br-2 grown on pectin medium	40	100	100	20	20	20
Br-2 grown on cellulose, pectin medium combined	70	100	100	10	10	20

\* Ten plants observed per treatment; percentages based on numerical scores of 1 = least decay and 10 = maximum decay.

pectin medium elicited a degree of acceleration in plant decay, greater with pectin than with cellulose and more so in the case of *M. spicatum* than with *M. heterophyllum*. The greatest effect was demonstrated by the application of the pectin or pectin-plus-cellulose cultured organism, in which case 100 percent of the plants succumbed. Perhaps the most striking confirmation of the addition effect of growth media on the induction of populations inimical to watermilfoil may be seen in Table 4. In this instance, a cyanobacterial group previously identified as an

Table 4  
Acceleration of Necrosis of *Myriophyllum* spp. by a  
Cyanobacterial Consortium and Angiosperm Growth Medium

Treatment	Inoculum size, ml	Percent Necrotic Plants*					
		<i>M. spicatum</i>			<i>M. heterophyllum</i>		
		Day 16	Day 21	Day 28	Day 16	Day 21	Day 28
Angiosperm medium	0.5	25	50	75	25	50	75
	1.0	75	75	75	25	25	50
	2.0	50	100	100	0	75	100
Cyanobacterial consortium	0.5	25	25	25	25	75	75
	1.0	25	50	25	0	25	25
	2.0	100	100	100	25	50	50

\* Ten plants observed per treatment; percentages based on numerical scores of 1 = least decay and 10 = maximum decay.

effective suppressant of milfoil was compared with the effect achieved by the addition of aliquots of sterile angiosperm medium in which the cyanobacteria were cultured. As may be seen, both organisms and culture medium achieved 100 percent acceleration of necroses of *M. spicatum*, while only the medium alone was as effective in the suppression of *M. heterophyllum*.

## DISCUSSION AND CONCLUSIONS

These data clearly confirm our working hypothesis, namely: that there is an extensive plant-associated community of microbial decomposers; that these cultured on the appropriate media can be induced to generate enzymes lytic to selected plant tissues; and that, further, there is a high degree of pathogenic specificity for isolates to the plants with which they are associated. There are three aspects of interest reflected in these data: first, the wide array of organisms that can be induced to accelerate the decay of the test plants; second, the much higher pathogenic potential of the isolates from *M. spicatum* to that species than to *M. heterophyllum*; and, finally, the seeming induction of a cellulolytic and pectinolytic microflora by the respective addition of sterile cellulose and pectin media to control chambers that provide a significant increase in necrosis over untreated controls.

One may feel with some confidence that the microbial agents for potential control of Eurasian watermilfoil are at hand. What remains to be achieved is a closer examination of the necrotic process in the plant itself: the establishment of inoculation strategies, inoculum thresholds, and the optimum point in the plant growth cycle for infection to be initiated.

## BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

### Preliminary Results of Large-Scale Pilot Testing of *Fusarium roseum* Culmorum as a Biocontrol Agent for Hydrilla

by

R. Charudattan,\* T. E. Freeman,\* R. E. Cullen,\* and F. M. Hofmeister\*

#### INTRODUCTION

An isolate of *Fusarium roseum* 'Culmorum' has been shown to be a useful and desirable biocontrol agent for hydrilla (Charudattan et al. 1980; Charudattan, Freeman, and Cullen 1981). The fungus was isolated from diseased *Stratiotes aloides* L. (Hydrocharitaceae) plants collected in The Netherlands, and has been highly effective in causing chlorosis, death, and rotting of hydrilla plants in numerous small-scale laboratory tests.

The fungus (referred to as Culmorum) produces a large number of canoe-shaped spores called macroconidia (conidia for short) on solid or liquid media. These conidia can be easily separated from mycelia and suspended in water to achieve desired conidial concentrations. In tests so far, conidial suspensions in water without additives have been used as inoculum. Inoculum concentrations in the range of  $2.5 \times 10^4$  to  $5 \times 10^4$  conidia per millilitre of treated water are necessary to kill hydrilla; higher levels of inoculum are generally consistently lethal to hydrilla (Charudattan and McKinney 1978).

The Culmorum-treated hydrilla becomes chlorotic in three days to a week. In about three weeks, especially at inoculum levels  $5 \times 10^4$  conidia per millilitre, the treated hydrilla may be totally decayed (Charudattan and McKinney 1978). The lethal damage caused by the Culmorum isolate has been repeatable under a variety of experimental conditions, and such lethal effects have not been produced by a number of other fungi tested against hydrilla in comparative tests (Charudattan and McKinney 1978).

Under suitable conditions of water quality, inoculum quality, and temperature, the Culmorum isolate parasitizes hydrilla. About 48 hr after the conidia settle on hydrilla shoots, they germinate and penetrate the leaf and stem cells. Although appressoria-like structures are produced on cell walls, the germinating mycelium appears to penetrate cells along grooves between adjoining cells. The fungus colonizes hydrilla tissue both epiphytically and endophytically. Chloroplasts in infected photosynthetic cells clump together, the cells discolor, and, subsequently, tissues begin to rot (Charudattan et al. unpublished).

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## OBJECTIVES

The large-scale pilot testing was intended: (a) to determine whether we can duplicate results of our small-scale studies with the *Culmorum* isolate on a larger scale under conditions that are closer to field conditions, and (b) to study the feasibility of producing one type of inoculum for large-scale operations.

## APPROACH

Three large-scale pilot tests were conducted between January and July 1981, inside a fiberglass greenhouse, in plastic pools measuring 3.04 m in diameter and 91 cm in height. Pools were prepared afresh for each test. The bottoms of pools were layered with sand, filled with irrigation water, and planted with terminal segments of hydrilla shoots (15 to 20 cm long) collected from Manatee Springs, Florida. The shoots were allowed to acclimatize for 2 to 3 weeks before treating with the fungus. Average water temperature in these tests ranged between ca. 19° and 29° C, depending on the season. The average light intensity was ca. 5500 lux at the water surface. Dissolved oxygen levels, temperature, and pH of water in the pools were monitored regularly during the tests.

One type of inoculum used in these tests consisted of an aqueous suspension of conidia. No adjuvants or carriers were used. Conidia were produced either in a Virtis microbial fermenter as submerged liquid culture or solid agar culture on 15-cm petri plates or conidia from both types of cultures were pooled. Potato dextrose broth and potato dextrose agar were used, respectively, for liquid and solid cultures. Typically, conidia were harvested from 3- to 4-week-old cultures. Conidia were washed by centrifugation at low speeds and resuspended in water at desired concentrations.

In the first test, one pool containing six different aquatic plant species was treated twice, first at the rate of  $5 \times 10^4$  conidia per millilitre of treated water and 30 days later at  $3.4 \times 10^4$  conidia per millilitre. Test plants were common arrowhead, coontail, eelgrass, hydrilla, southern naiad, and submerged growth of spatterdock. The test was terminated 49 days after the first inoculation, at which time damage to hydrilla and the other plants due to the *Culmorum* isolate was evaluated and the percentage of regrowth of hydrilla was estimated.

In the second pilot test, two comparable hydrilla pools were set up. One of them served as a fungus-free control while the other was treated twice with  $5 \times 10^4$  conidia per millilitre at a 44-day interval. The test was terminated after 64 days, at which time the degree of chlorosis, discoloration, and death was determined on 500 shoots collected along a randomly selected transect. Both treated and control hydrilla shoots were rated on a scale of 1 to 4, 1 being healthy, 2 and 3 being degrees of chlorosis and discoloration, and 4 being dead. The number of turions on sampled shoots and the number of tubers in a randomly selected square metre area were determined.

The third pilot test was similar to the second, except the inoculum consisted of germinated and nongerminated conidia roughly in a ratio of 1:18. Inoculum level was  $9.2 \times 10^4$  conidia per millilitre. Germination of conidia was accomplished by resuspending conidia in a broth at the rate of  $7.5 \times 10^5$  per millilitre and agitating the suspension in the Virtis microbial fermenter. The broth consisted of the following chemicals per litre: 10 g glucose, 1 g l-aspartic acid, 0.5 g yeast extract, 0.5 g  $K_2HPO_4$ , and 0.25 g  $MgSO_4 \times 7H_2O$ . Up to 90 percent of the conidia had germinated after a day, and to this suspension of germinated conidia in the broth were added fresh nongerminated conidia to yield the inoculum level mentioned. The control pool in this test received fungus-free, sterile broth. Damage to hydrilla shoots and the number of turions and tubers were determined as described before.

## RESULTS

Although our laboratory capabilities for inoculum production are limited, we could produce enough inoculum for large-scale experiments. Based on this experience, production of *Culmorum* inoculum for field tests (the next phase of study) is feasible, but collaboration with a fermentation industry will be necessary.

Empirically, a 9-cm petri plate can yield about  $3 \times 10^8$  conidia per plate per 20 ml of solid medium. To treat a pool of 152 cm radius and 30 cm water depth with an inoculum at the rate of  $5 \times 10^4$  conidia per millilitre,  $1.11 \times 10^{11}$  conidia would be needed. This many conidia can be obtained from about 8 l of solid medium, and would weigh as a thick paste ca. 96.5 g, or would equal 6.4 tablespoonsful.

In the first pilot test, except for southern naiad and hydrilla, the other plants did not show any adverse effects due to the *Culmorum* isolate. About 90 percent of southern naiad and hydrilla plants became chlorotic and discolored, and it was estimated that 5 percent of these plants had regrown at the completion of the test.

The results of the second and third pilot tests are presented in Table 1. The fungus-treated hydrilla had more damage than nontreated controls. There were more turions and tubers in the treated pool in the second test, but the tuber results were reversed in the third test.

Table 1  
Rating of Damage to Hydrilla and the Number of Turions and Tubers

Category	Treated	Control	Statistical Significance, 0.05 level
Avg. damage rating			
Second test	2.46	2.32	Significant
Third test	2.08	1.68	Significant
Avg. No. turions/shoot			
Second test	0.11	0.05	Significant
Third test	Too few to count		Not Applicable
No. tubers/m <sup>2</sup>			
Second test	154	124	Not Applicable
Third test	17	41	Not Applicable

In all three tests, the addition of the Culmorum inoculum had little effect on the dissolved oxygen levels and pH. The water temperatures of matched pools were comparable in the second and third tests.

## CONCLUSIONS

The production of Culmorum inoculum for large-scale experiments, for field studies, or for commercial use is not an unrealistic goal. It is relatively easy to produce enough conidia in the laboratory for large-scale pilot studies.

In the pilot tests, the Culmorum-treated hydrilla suffered more damage than nontreated controls. The effects of the fungus on the production turions and tubers are uncertain at this time.

The Culmorum-inflicted damage on hydrilla in the second and third tests was barely distinguishable from the senescence and death of older shoots in control pools. This factor led to the lack of appreciable differences between treated and control hydrilla.

The results of our small-scale tests, in which complete hydrilla kill was achieved, were not duplicated in the large-scale tests. Although in the first test 90 percent of the hydrilla shoots were chlorotic and discolored, total kill and disintegration of hydrilla tissues were not seen.

There is a need to reevaluate the type of inoculum and the method of inoculum production used in the large-scale tests. The use of conidial suspensions as inoculum may not be suitable in further studies. Other methods of inoculum production, especially methods that maintain the efficacy of inoculum, must be evaluated.

Although the results of the pilot tests are less satisfactory than anticipated, the potential for total hydrilla kill in these test systems cannot be discounted at this stage since we have not explored certain other methods of inoculum production and application that may ensure higher inoculum efficacy.

The preliminary results reported herein, therefore, are not a true indication of the Culmorum isolate as a control agent for hydrilla.

In our further evaluation of the Culmorum isolate emphasis will be on inoculum quality and efficacy.

## REFERENCES

- Charudattan, R., Freeman, T. E., and Cullen, R. E. 1981. "Evaluation of *Fusarium roseum* 'Culmorum' as a biological control for *Hydrilla verticillata*," *Proceedings of the 15th Annual Meeting of the Aquatic Plant Control Research Planning and Operations Review*, 17-20 November 1980, Savannah, Georgia, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 165-171.

- Charudattan, R., et al. 1980. "Evaluation of *Fusarium roseum* 'Culmorum' as a Biological Control for *Hydrilla verticillata*: Safety," E. S. Del Fosse, ed., *Proceedings of the V International Symposium on Biological Control of Weeds*, Brisbane, CSIRO, Australia, pp 307-323.
- Charudattan, R., and McKinney, D. E. 1978. "A Dutch Isolate of *Fusarium roseum* 'Culmorum' May Control *Hydrilla verticillata* in Florida," *Proceedings of the European Weed Research Society 5th Symposium on Aquatic Weeds*, EWRS Secretariat, Wageningen, The Netherlands, pp 219-224.

# BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

## Control of Waterhyacinth and Alligatorweed in Texas

by  
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### BACKGROUND

The Corps' Aquatic Plant Control Research Program (APCRP) is responsible for the development of new methodologies for the management of problem aquatic plant species in the Nation's waterways. One element of the APCRP involves the development of biological agents for the management of these troublesome aquatic plant species. Two particularly troublesome species that occur in Texas are waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.) and alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.). As a result of previous APCRP-sponsored research, three insect species have been discovered and released on waterhyacinth in the southern United States. These include the mottled waterhyacinth weevil (*Neochetina eichhorniae* Warner), the chevroned waterhyacinth weevil (*Neochetina bruchi* Hustache), and the Argentine waterhyacinth moth (*Sameodes albiguttalis* Warren). Three insect species have also been released on alligatorweed in the southern United States. These species include the alligatorweed flea beetle (*Agasicles hygrophila* Selman and Vogt), the alligatorweed stem-borer (*Vogtia malloi* Pastrana), and the alligatorweed thrips (*Amynothrips andersonii* O'Neill).

Records indicate that biological control agents in the past have not been extensively employed in Texas. During the mid-1970's,\*\* *N. bruchi* was released in two locations in Texas but never became established. None of the other species available for the management of waterhyacinth had ever been released in Texas. *Agasicles* and *Amynothrips* were both released on alligatorweed in Texas during the early 1970's. These agents have been less effective in controlling alligatorweed than the degree of control obtained in other areas (e.g., Louisiana and Florida). *Vogtia* was not released on alligatorweed in Texas.

After preliminary discussions of these problems with personnel of the U.S. Army Engineer District, Galveston (SWG), the WES submitted a proposal that provided a framework for the introduction and evaluation of all species of insects and plant pathogens available for the biocontrol of waterhyacinth and alligatorweed in Texas. In addition, the status of previously introduced insect species on alligatorweed was to be investigated, with special emphasis placed on the determination of environmental factors that may be limiting the effectiveness of these insects in controlling alligatorweed. Research efforts were initiated in June 1980.

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\*\* Personal communication, L. V. Guerra, Texas Parks and Wildlife Department, San Antonio, Texas, 1981.

## PURPOSE

This study was designed to:

- a. Establish, within the Galveston District, populations of all organisms impacting waterhyacinth and monitor their dispersal.
- b. Evaluate the impact of the various insects present on alligatorweed and make recommendations about the management of the insect populations.

## BIOCONTROL OF WATERHYACINTH

### Survey for biocontrol agents

During June 1980, waterhyacinths at four sites in southeastern Texas were examined for the presence of species of insects and plant pathogens capable of impacting the plant. These sites (Figure 1) included: J. D. Murphee state wildlife management area (JDM), located near Port Arthur in the North Coastal Area; Wallisville Reservoir, located 45 miles west of Beaumont in the Trinity River Basin; oxbow lake of the Brazos River at Richmond in the Brazos River Basin; and Hog Bayou, located approximately 15 miles south of Victoria in the Guadalupe River Basin. The only species found that had potential for impacting waterhyacinth

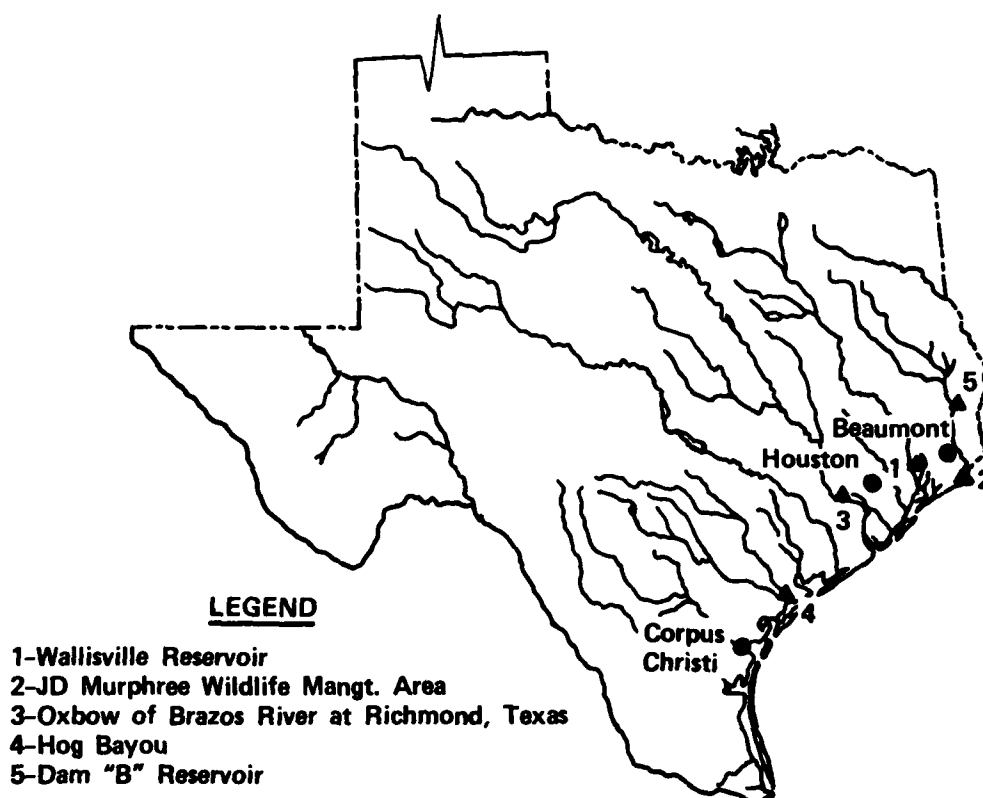


Figure 1. Texas site locations

were a noctuid moth, *Arzama densa* Walker, at the Wallisville Reservoir site; a galumnid mite, *Orthogalumna terebrantis* Wallwork, at the Wallisville Reservoir site; a spider mite, *Tetranychus* sp., at the Wallisville Reservoir and Hog Bayou site; and a fungal plant pathogen, *Cercospora piarope* Tharpe, at the Hog Bayou site. None of the insect species introduced into this country from South America as biocontrol agents of waterhyacinth were found. Based on the results of this survey, a decision was made to introduce *N. eichhorniae*, *N. bruchi*, and *S. albiguttalis* on waterhyacinth in Texas. After their establishment on the original release sites, insects from these sites would be released on waterhyacinth in other areas in which waterhyacinth was a problem. In addition to these introductions, experimental releases of the fungal plant pathogen, *Cercospora rodmanii* Conway, were to be made to determine the ability of this pathogen to impact waterhyacinth in Texas.

#### **Introduction of *Neochetina bruchi***

*Neochetina bruchi* was approved for release in the United States in 1974. A related species, *N. eichhorniae*, had been released in 1972, and had become widely distributed on waterhyacinth by the time *N. bruchi* was cleared for release. Consequently, *N. bruchi* was released in areas that already had established populations of *N. eichhorniae*. Because individuals of these species and their damage characteristics are very similar, field evaluation of *N. bruchi* in Florida and Louisiana was not feasible. Since neither species had become established on waterhyacinth in Texas, a study was initiated in June 1980 to evaluate the effectiveness of *N. bruchi* as a biocontrol of waterhyacinth. A study site was selected at the Wallisville Reservoir, and a total of 50 adult *N. bruchi* (30 males and 20 females) were released in August 1980. By December 1980, adults and larvae were found at the site, which indicated that the insects were reproducing. The presence of adults on the site in April 1981 confirmed that *N. bruchi* can successfully overwinter in Texas. However, the population on the release site was very low, and there was no evidence that *N. bruchi* had moved to other populations of waterhyacinth near the release site. By August 1981, the population of *N. bruchi* had increased to approximately 1 adult/2 waterhyacinth plants on the original release site, and typical *N. bruchi* feeding scars were observed on the leaves of waterhyacinth in populations one-fourth mile from the release site. Based on these findings, it was concluded that *N. bruchi* is now well established in the Wallisville Reservoir area. However, the population of the insect has not yet reached a sufficient level to significantly impact the waterhyacinth population.

#### **Introduction of *Neochetina eichhorniae***

Although *N. eichhorniae* was not found in Texas during the original survey in June 1980, adults were found in a borrow pit near the state route 73 highway bridge across Big Hill Bayou at the JDM in December 1980. This represented the first collection of *N. eichhorniae* from Texas, and it was assumed that its presence at this site was the result of a westward migration of the species from infested areas in Louisiana. Because the population level in December 1980 was very low and the ability of *N. eichhorniae* to overwinter was uncertain, a decision was made to

release additional *N. eichhorniae* at the JDM in 1981. In April 1981, 500 adults collected from field sites in Louisiana were released at the JDM. At that time, adult feeding scars were observed on waterhyacinths throughout the JDM, which indicated that the immigrant population of *N. eichhorniae* had successfully overwintered and was well established at the JDM. In September 1981, evidence of *Neochetina* feeding was observed at the Dam B Reservoir, located approximately 60 miles north of the JDM (Figure 1). Although the insects were too sparse to locate individuals, it is suspected that the feeding scars were produced by *N. eichhorniae*.

#### **Introduction of *Sameodes albiguttalis***

*Sameodes*, the most recent insect species to be approved for release in the United States as a biocontrol agent of waterhyacinth, was released at the JDM in April 1981. The release consisted of 2500 eggs, 1200 larvae, 45 pupae, and 7 adults. The release site was a rim canal inside the levee of Compartment 9 of the JDM. Although there has been no evidence of *Sameodes* on the site since the release was made, it is too early to determine whether or not the species has become established at the JDM. This is typical of the pattern shown by *Sameodes* in Louisiana and Florida. A year or longer may be required for sufficient population development that the insects may be observed. Also, it is common for *Sameodes* to persist on the original release site for one or two generations, after which the adults disperse to surrounding areas that have more suitable waterhyacinth plants. By September 1981, the plants at the original release site were tall and without bulbous petioles. Since *Sameodes* prefers the small, bulbous-petioled plants, it is probable that the population has dispersed to surrounding areas.

#### **Application of *Cercospora rodmanii***

*Cercospora rodmanii*, a fungal plant pathogen, was discovered in Florida in 1973. After several years of APCRP-sponsored developmental research, the University of Florida was granted a patent for its use as a biocontrol agent on waterhyacinth. Subsequently, the University gave production rights to Abbott Laboratories, Inc., which has since produced a potentially marketable formulation of the fungus. This formulation is being experimentally evaluated in Louisiana and Florida. However, data are needed from Texas on the performance and effectiveness of *C. rodmanii* in the formulation for inclusion in a petition for registration by EPA. For this reason, a decision was made to apply *C. rodmanii* to a 2-acre site at the JDM. After pretreatment data were collected, *C. rodmanii* was applied on 28 April 1981 at a rate of  $2.0 \times 10^5$  viable propagules per square metre, using a John Bean 1010-K piston-driven spray system with all in-line filters removed. By August 1981, leaves of waterhyacinth plants on the treatment site exhibited the punctate leaf spots characteristic of *C. rodmanii* infection. *Cercospora rodmanii* was isolated from leaf tissues collected from the site, thus confirming that *C. rodmanii* had successfully infected the plants. However, the degree of *C. rodmanii* infection of the treated plants remained at a low level through 1 September 1981, probably due to the high ambient temperatures experienced in the treatment area during July and August.

## BIOCONTROL OF ALLIGATORWEED

### Survey of biocontrol agents

Monitoring of biocontrol agents on alligatorweed has been conducted since June 1980 in three representative sites in southeastern Texas. These sites (Figure 1) include: JDM; Wallisville Reservoir; and Dam B Reservoir, located 15 miles west of Jasper in the Neches River Basin. In addition to examining plants on each site for the presence of the insect biocontrol agents, site conditions and quality of the alligatorweed on the sites were recorded. Based on these monitoring efforts, the following preliminary conclusions were drawn:

- a. *Agasicles* and *Vogtia* were widely distributed on alligatorweed in southeastern Texas, but *Amynothrips* was not present. Since *Vogtia* was not released in Texas, its presence reflected a westward migration of the species from infested sites in Louisiana.
- b. Although *Agasicles* was present on all sites, it was never found at population levels sufficient to significantly impact the alligatorweed populations.
- c. *Vogtia* was present in sufficient numbers to impact alligatorweed populations at the JDM and Dam B Reservoir study sites.
- d. Fluctuating water levels appeared to be the predominant factor influencing the development of insect species on alligatorweed in southeastern Texas.
- e. *Amynothrips* should be reintroduced on alligatorweed in Texas as soon as possible.

### Introduction of *Amynothrips andersonii*

To achieve the full complement of insect species on alligatorweed in Texas, a decision was made to introduce *Amynothrips* in May 1981. On 1 September 1981, approximately 4500 adults and nymphs were released at JDM. The insects used for the release were collected from field populations in Florida by personnel of the Aquatic Plant Operations Support Center, U.S. Army Engineer District, Jacksonville. The release site will be monitored through FY 82, and the site should serve as a source of *Amynothrips* for distribution to other areas of southeastern Texas in which alligatorweed is a problem.

### Further work

Based on our findings thus far, the following research efforts are planned for the next year.

#### a. *Waterhyacinth*:

- (1) The release sites for *N. bruchi* and *S. albiguttalis* will continue to be monitored and additional releases will be made at other problem sites.
- (2) The rate of development of the *N. eichhorniae* population will be monitored and, if needed, additional release sites will be established.
- (3) The site to which *C. rodmanii* was applied will be monitored to determine the rate of development of the infection and its impacts on waterhyacinth.

**b. Alligatorweed:**

- (1) The *Amynothrips* release sites will be monitored to determine if the species becomes established and overwinters. If the *Amynothrips* overwinters, additional site releases will be made.
- (2) Additional releases of *Agasicles* will be made at all three alligatorweed study sites in the spring of 1982. These sites should be monitored through the remainder of the year to determine the rate of population development.

# **LARGE-SCALE AQUATIC PLANT SURVEY METHOD FOR THE ARMY ENGINEER DISTRICT, GALVESTON, TEXAS**

by  
James M. Leonard\*

## **BACKGROUND**

During the summer of 1980, the U.S. Army Engineer Waterways Experiment Station (WES) implemented an assistance program for aquatic plant management for the Galveston District (SWG). Research at the WES (Dardeau 1982; Long 1979; Parris 1980) and elsewhere (Best, Wehde, and Linder 1981, and references within) has shown that, for many situations, aerial photographic surveys augmented by limited ground reconnaissance are cost-effective methods of accurately mapping aquatic macrophytes on a large scale.

## **OBJECTIVE**

Two primary objectives were specified for the assistance program:

- a. Determine how remote sensing and ground reconnaissance methodologies can be used in a problem identification and assessment plan to be implemented operationally by the SWG.
- b. Update the SWG portion of the 1971 General Design Memorandum "Aquatic Plant Control and Eradication State of Texas" by providing maps that accurately depict the current distribution and abundance of major problem plant species throughout the SWG.

## **APPROACH**

The two overall objectives of this program can be accomplished by successfully completing four tasks:

Task 1: Identify the problem species and define the areas of concern.

Task 2: Determine the best survey methods for identified areas and species.

Task 3: Plan and execute aerial photographic and ground reconnaissance surveys.

Task 4: Interpret survey data and map current distribution and abundance of problem species.

## **CURRENT STATUS**

### **Task 1**

The SWG and the WES jointly selected water bodies to be included in the new surveys. Figure 1 shows the State of Texas, the SWG boundary, and the general

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\*U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

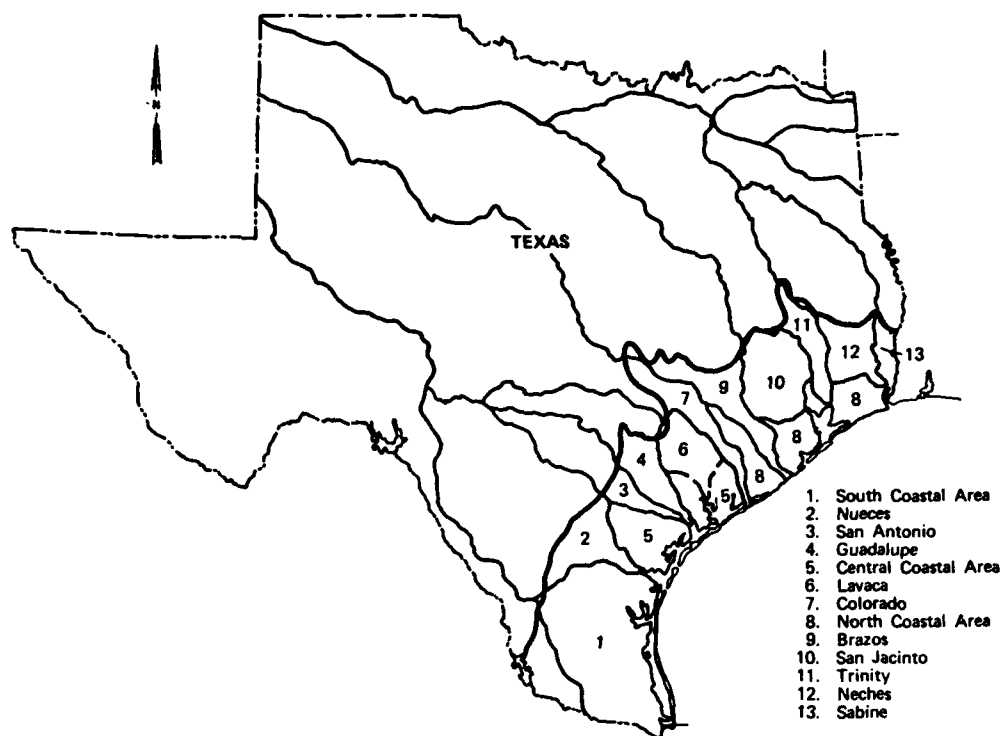


Figure 1. General locations of priority river basins for aerial survey of aquatic plants within the Galveston District

locations and names of the basins of greatest concern. Among these basins are several types of aquatic ecosystems: freshwater and saltwater marshes, estuaries, swamps, rivers, creeks, reservoirs, and natural lakes. Water clarity ranges from clear in mesotrophic lakes and streams to extremely turbid in eutrophic bayous and ponds. Three aquatic plant species of major concern were identified. These species, each of a distinct growth form, were: hydrilla (*Hydrilla verticillata*), a rooted submersed aquatic species; waterhyacinth (*Eichhornia crassipes*), a floating species; and alligatorweed (*Alternanthera philoxeroides*), a rooted emergent species.

## Task 2

Procedures generally recommended for aquatic plant surveys of large areas combine low altitude aerial photography with limited, onsite ground reconnaissance (see Dardeau (1982) for specific examples). The term "ground truth" refers to a ground reconnaissance used to provide enough onsite observations to allow reliable interpretation of aerial photographs. Aerial photography augmented by only limited ground truth can be used to accurately map floating and emergent plant populations in habitats that support macrophyte communities dominated by one or few species. The same limited population diversity allows minimal use of ground truth when aerially surveying submersed plants in relatively clear waters. For waters where light penetration is limited, or where several equally abundant

species are present, more extensive ground truth is required. Streams overhung by vegetation must be surveyed solely using ground reconnaissance.

The diverse habitats and growth forms of the three target species make selection of a single suitable survey method for all the areas of concern unlikely. A compounding problem is that numerous techniques exist for obtaining survey data. Ground reconnaissance survey techniques are the simplest. Various film types and imagery scales complicate the selection of an aerial photographic survey technique. Studies were performed in 1980 to determine which film types and scales were best for mapping hydrilla, waterhyacinth, and alligatorweed in the basin of concern. These studies are described in detail elsewhere (Leonard and Payne 1981; Dardeau 1982) and only part of the results shall be summarized herein. Imagery scales of 1:12,000 proved suitable for accurately detecting hydrilla, waterhyacinth, and alligatorweed populations. True color film proved best for detecting submersed hydrilla, while false color (infrared) film proved best for detecting floating waterhyacinth and emergent alligatorweed.

Once the best film types and imagery scales had been determined, field surveys of selected points along each of the 13 basins shown in Figure 1 were performed. There were two objectives for these surveys: to collect enough initial data on the basins to determine where the three problem species occurred or were likely to occur, and to determine which portions of each basin would require more extensive ground reconnaissance. These surveys were completed during the summer of 1981. Data analyses and the beginning of subsequent planning and execution of large-scale aerial and ground surveys are scheduled for 1982.

### **Task 3**

The basic survey photomission recommended by the WES for all the target areas within the SWG is to obtain 1:12,000-scale, stereo, true color photographic images of the area of interest where submersed hydrilla is known or suspected to occur. In those locations where emergent or floating plant species are of major concern, false color infrared film (e.g. Kodak Aerochrome infrared film 2443) should be used. More specific planning of how much ground reconnaissance will be necessary for each basin depends upon completion of FY 82 data analysis. For any single imagery scale, cost per unit area (acre) varies mainly with the size of the area photographed. Price quotes from independent contractors (1980) for producing 1:12,000-scale images range from \$0.05 to \$0.02 per acre photographed.

### **Task 4**

The final task of extracting data from the photographic images, whether they be color or color infrared, can be accomplished in four steps. First a 1:12,000-scale semicontrolled photomosaic (Figure 2) is produced by a contractor. Then a transparent base map is constructed by tracing the boundaries of the target water body onto a transparent material such as mylar. Thirdly, photographs are positioned precisely under this transparent base map so that locations of the plants can be traced onto the base map (Figure 3). As introduced in Task 2, the ground

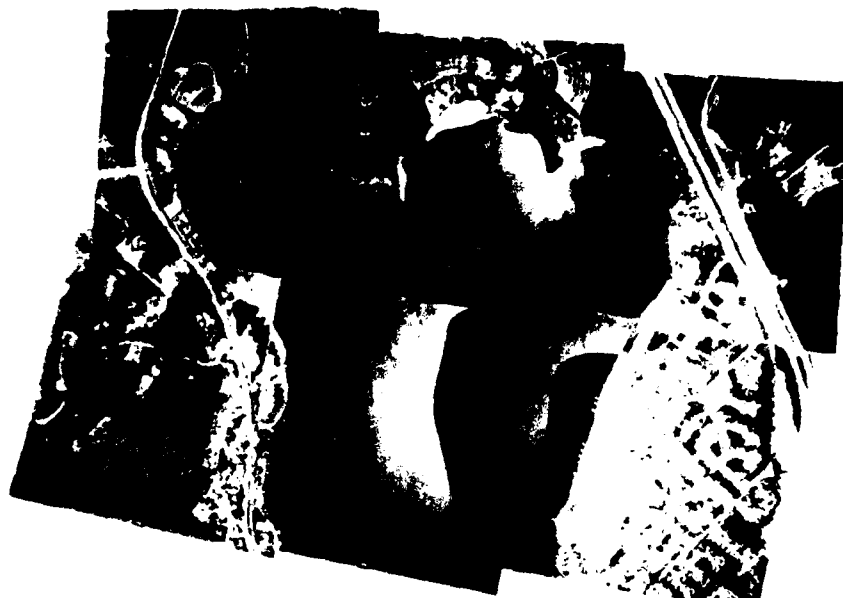


Figure 2. Semicontrolled photomosaic (reduced for printing)



Figure 3. Tracing photointerpreted data onto a transparent base map

truth information is used as a visual reference to allow reliable photointerpretation. Ground reconnaissance data provide the only basis for mapping plant population boundaries in habitats inaccessible to aerial photography. Aerial estimates of plant populations can be made by a simple dot count method. This consists of using a Bruning Areagraphic Chart No. 4849. When used according to directions, this chart has an accuracy of 97 percent. Briefly, the interpreter counts the dots within the plant boundaries mapped on the transparent overlays (Figure 4). Then the dot counts are converted to acreage using the following equation:

$$A = \text{Number of dots} \times SF$$

where

A = aerial coverage of plants, acres

SF = scale factor (i.e., acreage value of one dot). For 1:12,000-scale and chart No. 4849, SF = 0.22957.

With minimal training and minor purchases of equipment, in-house personnel can perform all photointerpretation and final map production.

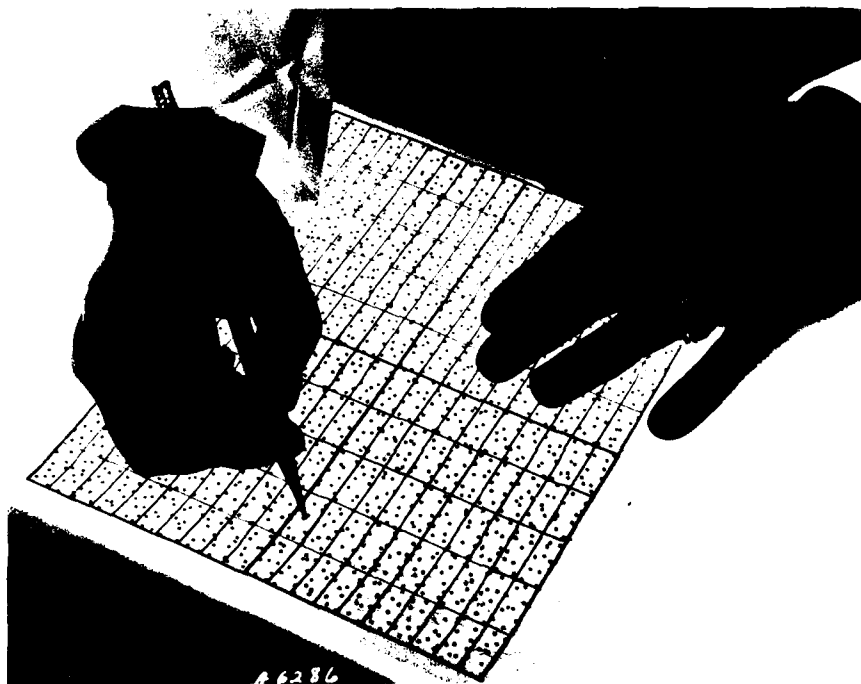


Figure 4. Dot count method of estimating area from photointerpreted data

## REFERENCES

- Best, R. G., Wehde, M. E., and Linder, R. L. 1981. "Spectral Reflectance of Hydrophytes," *Remote Sens. Environ.* Vol 11, pp 27-35.
- Dardeau, E. A., Jr. 1982. "Remote-Sensing Procedures Applied to Mapping and Monitoring Aquatic Plant Population — Four Case Studies" in preparation, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Leonard, J. M., and Payne, B. S. 1981. "Demonstration of Techniques for Aerial Photographic Mapping of Aquatic Plant Populations in the Galveston District," Letter Report to the U.S. Army Engineer District, Galveston, Galveston, Tex.
- Long, K. S. 1979. "Remote Sensing of Aquatic Plants," Technical Report A-79-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Parris S. D. 1980. "Development of Techniques for Large-Area Surveys of Aquatic Plants in Panama and Texas," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-20 November 1980, Savannah, Ga.*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 69-78.

# IMPROVED TIMING OF CONTROL MEASURES FOR EURASIAN WATERMILFOIL AND HYDRILLA IN LAKE SEMINOLE

by  
James M. Leonard\*

## BACKGROUND

Aquatic plants produce carbohydrates through photosynthesis during the growing season. Carbohydrates produced in excess of immediate respiratory demands can be accumulated in the stems and leaves through the summer. Toward the end of the growing season, perhaps in response to decreasing temperature and photoperiod, these excess carbohydrates can be translocated to the roots and used for overwintering and subsequent early spring regrowth of shoots (Titus 1977). This seasonality in carbohydrate production, storage, and utilization may be an important aspect of the physiological ecology of submersed plants that can be taken advantage of during plant control efforts. Independent work by Perkins (1980), Perkins and Systma, (1981) and Titus and Adams (1979) suggest that, by timing standing crop removal techniques at critical times throughout the year, it may be possible to remove the excess carbohydrates before they are translocated to the roots in fall and shoots in spring. Timely removal of the standing crop and accumulated carbohydrates, by preventing most translocation, may reduce subsequent spring growth. Thus, the long-term efficacy of control measures could be increased. The present study was designed to determine if and when carbohydrate mobilization and translocation occur in populations of milfoil (*Myriophyllum spicatum*) and hydrilla (*Hydrilla verticillata*) in Lake Seminole, Florida, a Corps of Engineers reservoir in the Mobile District. Also, this study will examine the operational utility of timing control treatments with these carbohydrate shifts in order to maximize the duration of treatment effects.

## OBJECTIVES

The objectives of this study were to determine:

- a. The rate and timing of carbohydrate production and translocation.
- b. If the timing of conventional contact herbicide treatments affects the rate or timing of carbohydrate production or translocation.
- c. If selected, easily measured environmental parameters (e.g., air and water temperature, day length, pH, dissolved oxygen, and conductivity) are related to the onset of carbohydrate translocation in the plants.

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ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/G 6/6  
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## MATERIALS AND METHODS

Site selection and initial fieldwork began in March 1981. Six 1/2-acre plots were selected with the aid of the Lake Seminole Resource Manager. Three plots contained nearly homogeneous stands of milfoil, and the other three contained nearly homogeneous stands of hydrilla. The individual plots were separated by about 150 to 200 yards. The milfoil plots were located 1.5 miles from the hydrilla plots. Both sets of plots were located between the Fish Pond Drain and the Spring Creek arms of the reservoir (Figure 1). Individual plots were marked using anchored buoys. Figure 2 shows the typical plot and subplot design. Figure 3 is a photograph of the hydrilla plots. Sediment samples were taken in March 1981 using a pipe dredge and analyzed for major plant nutrients (total Kjeldahl nitrogen, total phosphorus, and total organic carbon).

Monthly estimates of plant heights within each plot were made using a Raytheon Recording Fathometer. A series of fathometer tracings were made over each plot using the grid marker buoys as guidance points (Figure 4). Figure 5 is a typical fathometer tracing showing milfoil heights.

Biomass samples were taken quarterly at three randomly selected subplots within each of the six treatment plots, using the WES biomass sampler (Figure 6). The biomass sampler takes a 0.72-ft<sup>2</sup> sample of short material within the randomly selected subplot. The samples were analyzed for dry weight and ash-free dry weight of the plant material collected.

Monthly water quality analyses were conducted at a subsurface depth of 2 ft within each of the plots using a Hydrolab instrument package that measured temperature, conductivity, dissolved oxygen, and pH. Light penetration was measured along with these analyses using Secchi's disk. Daily photoperiod, precipitation, and air temperature data were provided by a local recording station of the National Oceanic and Atmospheric Administration (NOAA).

Within each of the six plots, whole plant (i.e., intact roots and shoots) samples (Figure 7) were collected with a sediment scoop (Figure 8). These plant samples were collected monthly from two randomly selected subplots. Sampled plants were used for carbohydrate analyses. The plants were rinsed free of periphyton and debris; roots and shoots were separated and placed in plastic trays (Figure 9). Tissues were then freeze-dried at -50° C for 48 hr using a Virtis model 50-SRC-8 freeze dryer. Then, 4 to 5 g of freeze-dried shoot or root tissue was pulverized; carbohydrates were extracted first using 80 percent ethanol and then boiling water (Perkins and Systma 1981). These extracts were analyzed by the WES Analytical Lab Group (ALG) using the phenolsulfuric acid colorimetric technique of Dubois et al. (1956). This procedure yielded estimates of carbohydrates comparable to those reported as total nonstructural carbohydrates (TNC) by Titus (1977).

To assess the effect of biomass removal by a contact herbicide on carbohydrate physiology, endothall was applied to one each of the milfoil and hydrilla plots on 13 May 1981. Endothall was applied just after all routine monthly sampling described

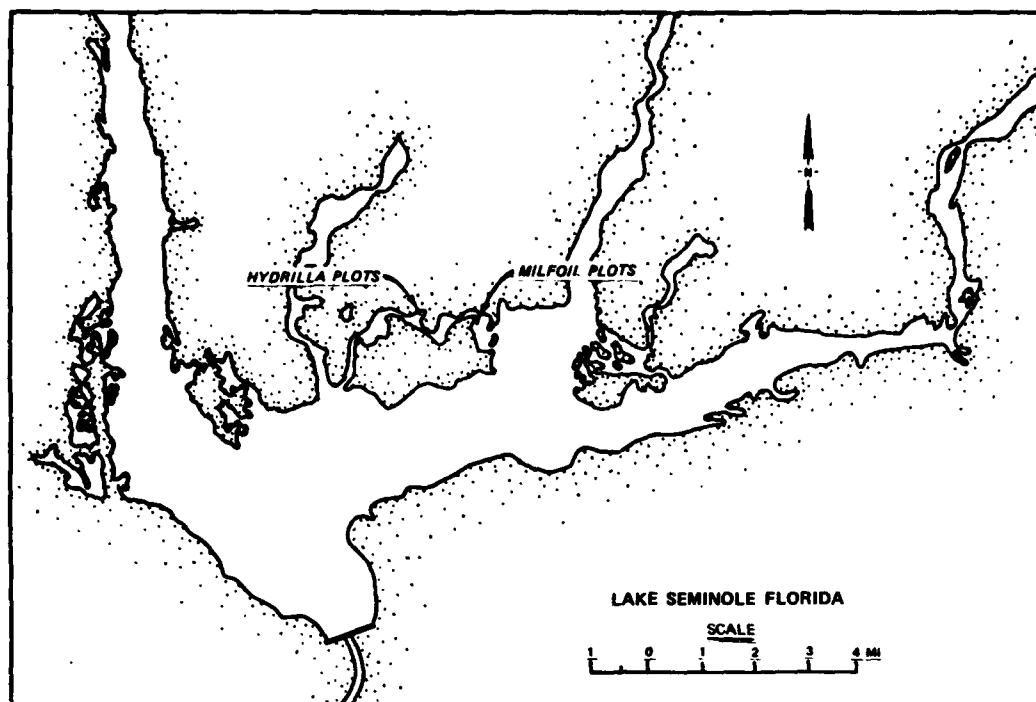


Figure 1. Lake Seminole Florida carbohydrate research plots

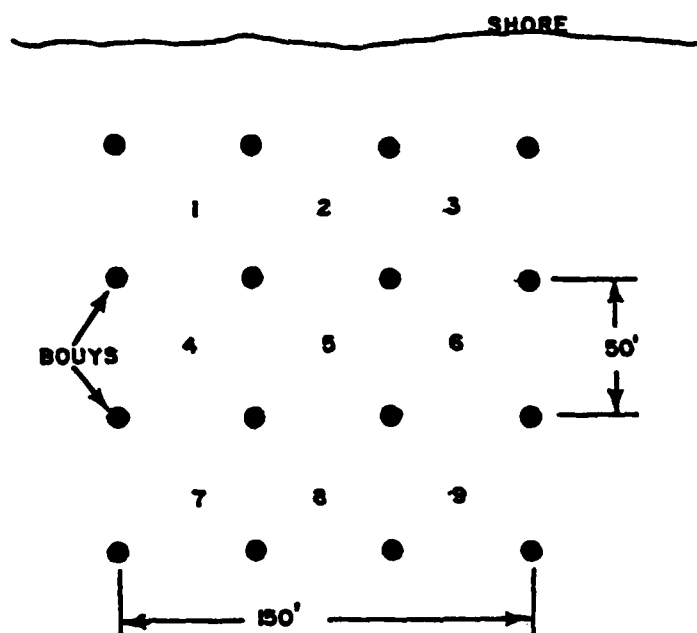


Figure 2. Plot and subplot (1-9) design



Figure 3. Hydrilla carbohydrate test area, Lake Seminole Florida, March 1981

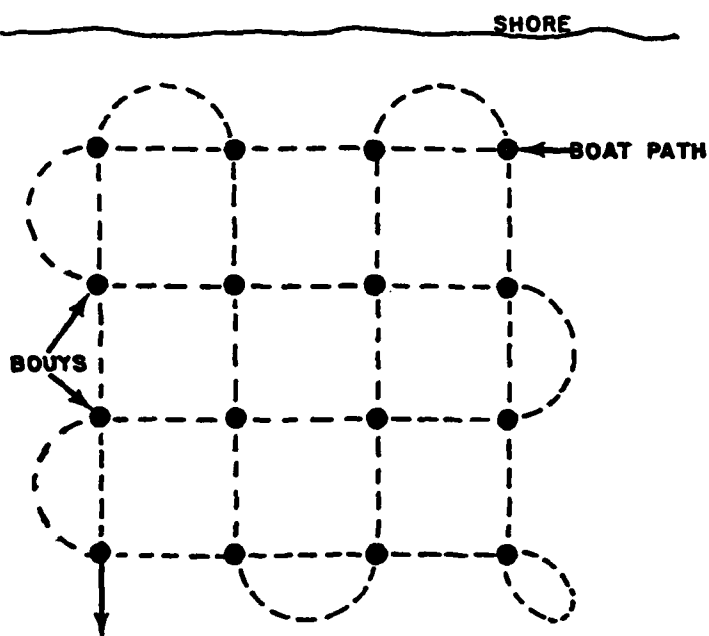


Figure 4. Fathometer tracing route



FATHOMETER TRACING OF SUBMERGED EURASIAN WATERMILFOIL




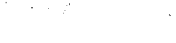
 SURFACE NOISE  
 FLOATING PLANT MATS  
 SUBMERGED PLANTS  
 LAKE BOTTOM

Figure 5. Fathometer data of Eurasian watermilfoil, Lake Seminole, Florida

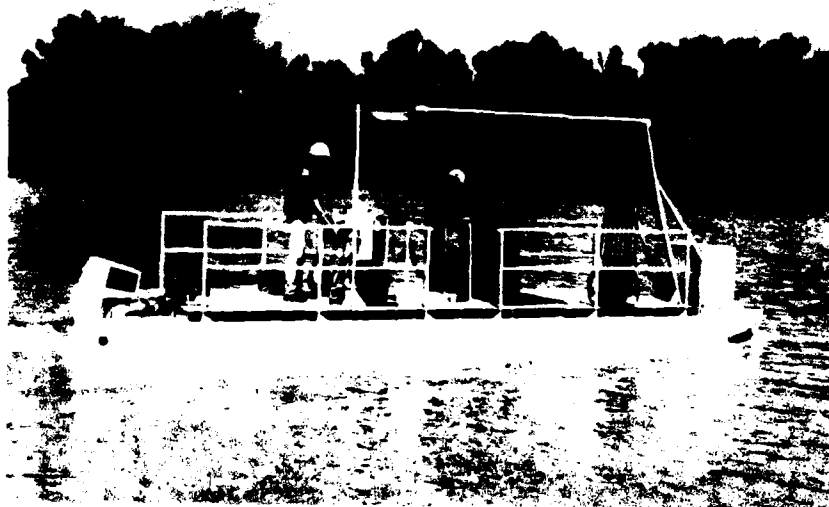


Figure 6. WES biomass sampler



Figure 7. Eurasian watermilfoil whole plant sample for carbohydrate analysis

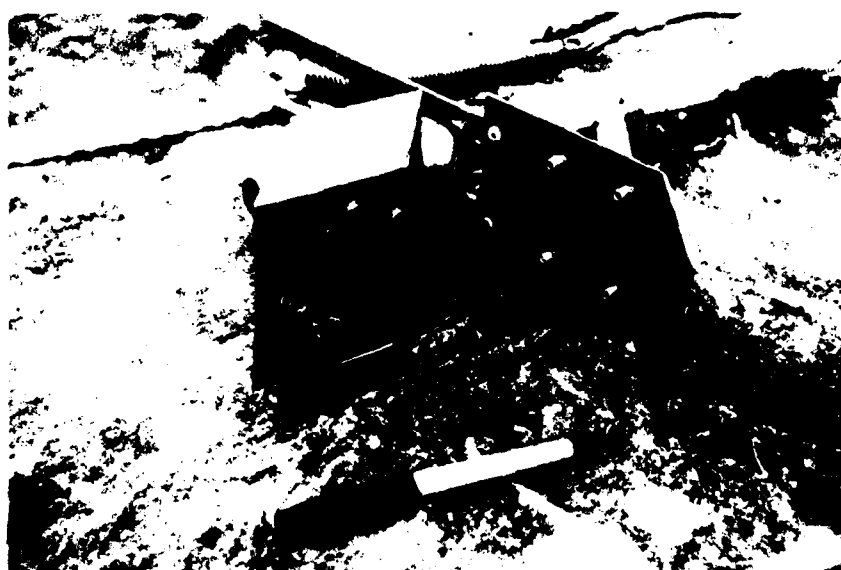


Figure 8. Sediment scoop used for obtaining whole plant samples



Figure 9. Plastic trays containing milfoil shoots (left) and roots (right)

above had been completed. This application date coincided with the usual timing of past operational treatments. The effects of herbicide treatment on water quality as well as plant height, biomass, and carbohydrate concentrations will be monitored throughout the summer, fall, and winter. Second endothall applications to one each of different milfoil and hydrilla plots are scheduled for 9 November 1981. Effects of these fall treatments will be assessed identically to the spring treatment.

### PRELIMINARY RESULTS

Chemical analyses of March 1981 sediment samples showed some interplot differences in total Kjeldahl nitrogen, total phosphorus, and total organic carbon (Table 1). However, none of the observed values were considered limiting to plant growth.

Table 1  
Sediment Data for Carbohydrate Translocation  
Research Plots, March 1981

Plot	Total Kjeldahl Nitrogen mg/kg	Total Phosphorus mg/kg	Total Organic Carbon mg/kg
Milfoil control	3,450	352	29,300
Milfoil control (dupl)	3,520	402	14,300
Milfoil 1	1,590	197	14,300
Milfoil 2	3,580	354	29,300
Hydrilla control	2,800	311	17,900
Hydrilla 1	2,960	371	27,300
Hydrilla 2	1,630	162	13,200

Fathometer data analyses to date show normal increase in plant height through the spring and summer. These data show short standing crops in March and April. Rapid growth to near topped-out conditions occur in May. By June, dense topped-out stands are observed. Figure 10 shows this dense, topped-out condition in a portion of a hydrilla plot in July 1981.

To date, water quality values are similar between plots (Table 2). Temperature increases through summer coincide with increases in plant standing crop.

Carbohydrate analyses of root and shoot samples are continuing. Figures 11 and 12 show carbohydrate concentrations in shoots and roots from March through October. Data from two untreated plots of both hydrilla and milfoil were averaged to produce the upper graph on each figure. A marked peak in carbohydrate concentration between March and May is noticeable in both root and shoot tissue samples from all plots of both species. The physiological foundations of these peaks will be better understood after data have been obtained for a full calendar year.

Fathometer tracings and visual observations indicate that the endothall treatment produced a pronounced decrease in standing crop of hydrilla and a moderate decrease of milfoil. Both species were damaged physically, but root or shoot carbohydrate concentrations were not affected. Water quality analyses made 1 month after treatment revealed a slightly lower concentration of dissolved oxygen in treated versus control plots. These reduced oxygen levels are probably the result of decreased photosynthesis and oxidation of decaying plant material.



Figure 10. Lake Seminole hydrilla carbohydrate research plot, July 1981

**Table 2**  
**Water Quality Values, Carbohydrate Test Plots**  
**Lake Seminole, Florida, 1981**

<i>Parameter</i>	<i>17 Mar</i>	<i>8 Apr</i>	<i>12 May</i>	<i>9 Jan</i>	<i>7 Jul</i>	<i>4 Aug</i>	<i>1 Sep</i>	<i>9 Oct</i>	<i>4 Nov</i>
<b>Milfoil control</b>									
Temperature, °C	16.8	21.1	24.3	29.7	31.0	29.8	29.7	27.0	20.1
Conductivity, $\mu$ mhos/cm	159	169	142	118	127	153	138	140	143
Dissolved oxygen, mg/l	9.0	9.8	9.3	8.1	8.7	-	9.6	8.6	10.0
pH	8.2	8.3	8.6	8.2	8.5	7.8	8.5	8.6	8.4
Secchi disk, ft	9.0	12.0	7.0	11.0	8.5	7.0	10.5	9.0	12.0
<b>Milfoil 1</b>									
Temperature, °C	16.7	21.3	24.1	29.5	31.7	29.7	30.4	27.3	19.8
Conductivity, $\mu$ mhos/cm	159	168	146	120	127	155	137	127	147
Dissolved oxygen, mg/l	8.8	10.3	8.1	7.0	7.7	-	8.5	11.1	9.4
pH	8.2	8.3	8.3	7.9	8.6	7.8	8.3	8.9	8.0
Secchi disk, ft	9.0	12.0	7.0	11.0	8.5	7.0	10.5	9.0	12.0
<b>Milfoil 2</b>									
Temperature, °C	16.7	21.2	23.7	29.5	31.1	30.1	30.5	27.8	19.6
Conductivity, $\mu$ mhos/cm	159	171	146	115	127	147	138	142	146
Dissolved oxygen, mg/l	9.4	8.8	8.0	7.6	8.0	-	9.2	8.5	9.7
pH	8.2	7.9	8.2	8.3	8.7	8.0	8.4	8.6	7.8
Secchi disk, ft	9.0	12.0	7.0	11.0	8.5	7.0	10.5	9.0	12.0
<b>Hydrilla control</b>									
Temperature, °C	17.4	21.3	23.5	29.8	30.7	29.7	29.3	27.1	20.4
Conductivity, $\mu$ mhos/cm	159	161	133	108	98	90	95	92	97
Dissolved oxygen, mg/l	9.1	8.6	7.8	8.4	10.2	9.9	9.2	10.0	10.1
pH	8.1	7.7	7.6	8.0	8.7	8.8	8.8	9.0	8.8
Secchi disk, ft	9.0	9.5	8.0	11.0	11.0	9.0	11.0	9.5	12.0
<b>Hydrilla 1</b>									
Temperature, °C	17.3	21.4	23.6	29.9	30.9	30.5	29.4	26.6	20.4
Conductivity, $\mu$ mhos/cm	158	160	131	107	97	87	92	88	99
Dissolved oxygen, mg/l	8.2	8.4	7.7	8.2	10.8	9.3	11.8	11.0	10.2
pH	8.0	7.7	7.6	8.0	8.7	8.7	9.2	9.2	8.8
Secchi disk, ft	9.0	9.5	8.0	11.0	11.0	9.0	11.0	9.5	12.0
<b>Hydrilla 2</b>									
Temperature, °C	17.3	21.5	23.9	29.9	30.1	30.1	29.2	26.2	20.0
Conductivity, $\mu$ mhos/cm	158	159	128	110	107	104	97	95	99
Dissolved oxygen, mg/l	8.3	8.6	8.1	8.0	9.0	8.2	9.6	9.0	10.0
pH	8.0	7.7	7.8	8.0	8.5	8.5	8.8	9.0	8.8
Secchi disk, ft	9.0	9.5	8.0	11.0	11.0	9.0	11.0	9.5	12.0

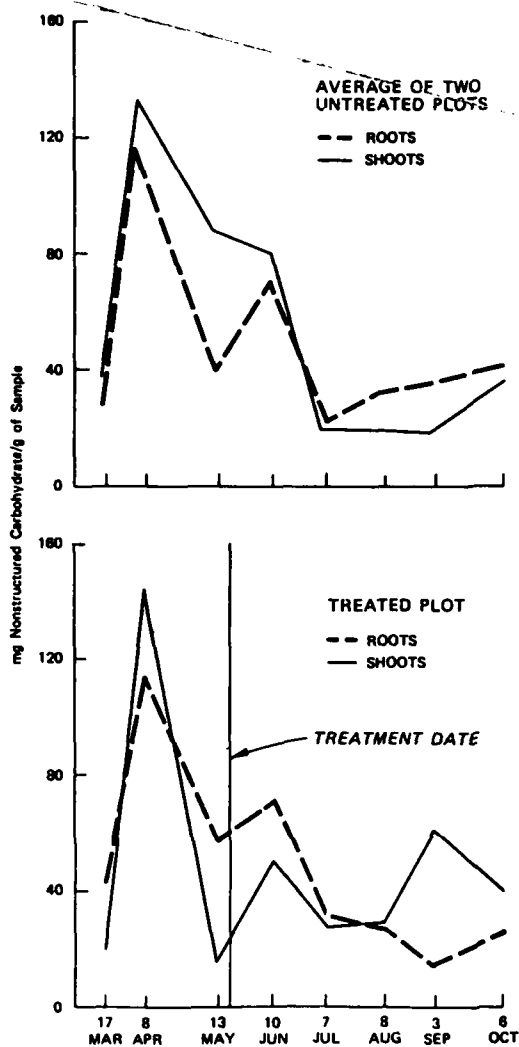


Figure 11. Concentrations of nonstructured carbohydrates found in samples of roots and shoots in milfoil, Lake Seminole, Florida

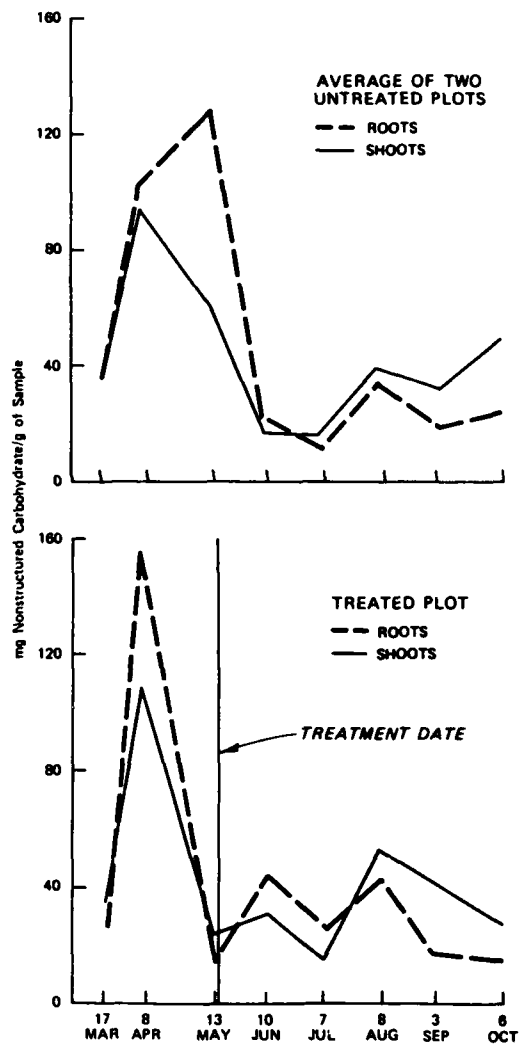


Figure 12. Concentrations of nonstructured carbohydrates found in samples of roots and shoots in hydrilla, Lake Seminole, Florida

## PRELIMINARY CONCLUSIONS

The following are preliminary conclusions:

- a. Fathometer data and visual observations of all plots showed that milfoil reached topped-out conditions by mid-June and hydrilla by early July. This appears to be true for most milfoil and hydrilla stands in the vicinity of Spring Creek and Fish Pond Drain.
- b. The standing crop biomass of both species increased with day length and water temperature and peaked by mid-June to early July.
- c. A surge in carbohydrate concentrations was detected in both root and shoot tissues sampled from all plots between mid-March and mid-May. This surge preceded both biomass and water temperature upswings and appeared to signal the beginning of spring growth.
- d. Spring endothall treatments produced substantial physical damage to all treated plants. The long-term effects on biomass and carbohydrate physiology will be observed as samples of spring regrowth are taken and analyzed.
- e. Fall endothall treatments will be applied in early December 1981. The effects of these treatments on biomass and carbohydrate physiology will be observed as studies are continued.

## REFERENCES

- Dubois, M., et al. 1956. "Colorimetric Method for Determination of Sugars and Related Substances," *Anal. Chem.*, Vol 28, pp 350-356.
- Perkins, M. A. 1980. "Evaluation of Selected Nonchemical Alternatives for Aquatic Plant Management," Municipality of Metropolitan Seattle (METRO), Seattle, Wash.
- Perkins, M. A., and Systma, M. D. 1981. "Efficacy of Mechanical Harvesting and Its Influence Upon Carbohydrate Accumulation in Eurasian Watermilfoil," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-20 November 1980, Savannah, Ga.*, Miscellaneous Paper A-81-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 464-479.
- Titus, J. E. 1977. *The Comparative Physiological Ecology of Three Submerged Macrophytes*. Ph.D. Thesis, University of Wisconsin-Madison, Madison, Wis.
- Titus, J. E., and Adams, M. S. 1979. "Comparative Carbohydrate Storage and Utilization Patterns in the Submerged Macrophytes, *Myriophyllum spicatum* and *Vallisneria americana*," *Amer. Midld. Nat.*, Vol 102, pp 263-272.

# LARGE-SCALE OPERATIONS MANAGEMENT TEST WITH INSECTS AND PATHOGENS FOR THE CONTROL OF WATERHYACINTH IN LOUISIANA

by  
Edwin A. Theriot\*

## INTRODUCTION

The Large-Scale Operations Management Test with insects and pathogens (LSOMT-IP) is being conducted for and funded by the New Orleans District. A test plan was developed in 1979 to evaluate a number of insects and pathogens on an operational level for the control of waterhyacinth.

## PURPOSE

The purpose of this study is to develop and demonstrate an operational capability for the use of selected combinations of insects and plant pathogens for the control of waterhyacinth.

## TEST ORGANISMS

The organisms being evaluated are: a fungal plant pathogen, *Cercospora rodmanii*; *Arzama densa*, a native noctuid moth; *Sameodes albigutallis*, an introduced pyralid moth; and the introduced waterhyacinth weevils, *Neochetina eichhorniae* and *N. bruchi*.

## LSOMT

### **Cercospora rodmanii**

*Cercospora rodmanii* is a fungal pathogen that was isolated from diseased waterhyacinth taken from Rodman Reservoir in 1973. Dr. Conway of the University of Florida conducted studies that found *C. rodmanii* to be suitably host specific for use as a biocontrol agent. The University obtained the patent rights to the organism and subsequently granted Abbott Laboratories (AL) of Chicago, Ill., the rights to develop a product form for sale and distribution. It is this formulation of *C. rodmanii* which is being evaluated in the LSOMT-IP.

**Preliminary studies.** Under the auspices of the LSOMT-IP, two preliminary studies were conducted using the formulation, prior to the large-scale applications. The first was an evaluation of infectivity and pathogenicity of the formulation. The study was conducted at the U.S. Army Engineer Waterways Experiment Station (WES) in outdoor tanks in 1979. It was concluded from the study that:

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\*U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

- a. The Abbott Laboratories formulation of *C. rodmanii* was infectious on waterhyacinth.
- b. Hyphal tissues produced by the original inoculum proliferated throughout the waterhyacinth tissues.
- c. Secondary infection on new waterhyacinth tissues occurred from conidia produced on the originally infected plants.
- d. Vegetative reproduction of a waterhyacinth was significantly reduced.
- e. A treatment rate of  $4 \times 10^6$  CFU\*/m<sup>2</sup> produced a heavy infection on waterhyacinth.

Details of the study are presented in WES Technical Report A-81-5.

The second preliminary study was conducted to evaluate the infectivity of the *C. rodmanii* formulation using two application systems. With the assistance of Louisiana's Department of Wildlife and Fisheries, the study was conducted in a canal site in south Louisiana in 1979. It was concluded from the results that:

- a. *Cercospora rodmanii* contained in the formulation can infect field populations of waterhyacinth in Louisiana.
- b. *Cercospora rodmanii* contained in the formulation can be applied with either a low-pressure impeller pump at 25 psi or a high-pressure piston pump system of 150 psi with no significant differences in infectivity.

With the results of the preliminary studies, AL was able to obtain an experimental use permit from the Environmental Protection Agency for large-scale applications.

**Large-scale studies.** The first large-scale application was conducted in April of 1980 on 4.5 acres of waterhyacinth near Lake Theriot in southeastern Louisiana. The formulation was applied with a fixed winged aircraft.

Thus far we have concluded that:

- a. Abbott Laboratories formulation of *C. rodmanii* has infected the site.
- b. The formulation can be applied on a large scale with conventional aerial application equipment.
- c. *Cercospora rodmanii* has produced a significant reduction in the biomass of waterhyacinth in the test site.

The second large-scale application was conducted on 6.4 acres of waterhyacinth near Centerville in south-central Louisiana in April of 1981. The formulation was applied in the same manner, using an airplane.

Thus far it can be concluded that the formulation of *C. rodmanii* has infected the waterhyacinth population in the sites but it seems to have been much slower than the Lake Theriot site.

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\*CFU = Colony forming units.

### **Arzama densa**

*Arzama densa* is a native noctuid moth. It can be devastating on waterhyacinth, but is very sporadic in occurrence due to parasitic insects and microorganisms. We felt that if the insects could be mass reared and released on a site in large numbers, control could be achieved.

**Preliminary studies.** The U.S. Department of Agriculture (USDA) in Stoneville, Miss., was funded to develop the mass-rearing capability. Dr. Ron Bear was able to produce an artificial diet on which he could carry the insects through several generations. Once this capability was achieved, the first preliminary field study was conducted.

**Field studies.** Several thousand *Arzama* larvae were released and tested on a canal site in southeast Louisiana in July of 1980. The insects were tested at two rates, the highest of which was one larva per six plants. Late instar larvae contained in waterhyacinth petioles were sown by hand over the test site.

The results of the study were inconclusive. A slight reduction in biomass was noted, but no open water was produced.

A second preliminary study was conducted at Lake Salvador in southeastern Louisiana in April 1981. *Arzama* eggs suspended in a xanthane gum solution were applied with a garden applicator at a rate of 1 egg per plant.

The results were disappointing: no appreciable reduction in biomass or densities. It was determined at that point to hold off on the large-scale application of *A. densa* to reassess its possibilities as a biocontrol agent for waterhyacinth.

### **Sameodes albiguttalis**

With funds provided by the WES Aquatic Plant Control Research Program (APCRP), *Sameodes albiguttalis* was collected in Argentina, brought through extensive quarantine studies, and released in the United States by the USDA as a biological control agent on waterhyacinth. It was subsequently included in the test scenario for the LSOMT-IP for evaluation on an operational scale.

**Release.** The first release of *Sameodes* in Louisiana took place in September 1979 at the Lake Salvador canal site. Plant tissues, taken from our greenhouse facilities, which were infested with various life stages of the insect, were placed among the existing waterhyacinth population. Verification of establishment of a population of *Sameodes* and its overwintering ability was obtained in the spring of the following year. Several larvae and adults were collected near the release site.

A second release of *Sameodes* was made on the same day at the Lake Theriot canal site. No indication of establishment could be found until the fall of 1981 when the insects were collected near the release site. Two subsequent releases have been made to establish *Sameodes* throughout southern Louisiana.

**Establishment.** In September 1981, we conducted a survey for *Sameodes* throughout south Louisiana. We discovered that the insects have become well established in at least 13 new locations (Figure 1). These new colonies are a result of

- RELEASE SITE WHERE *S. albiguttalis* HAS BEEN ESTABLISHED
- RELEASE SITE WHERE *S. albiguttalis* HAS NOT ESTABLISHED
- ▲ AREAS WHERE *S. albiguttalis* HAS SPREAD AND BECOME ESTABLISHED

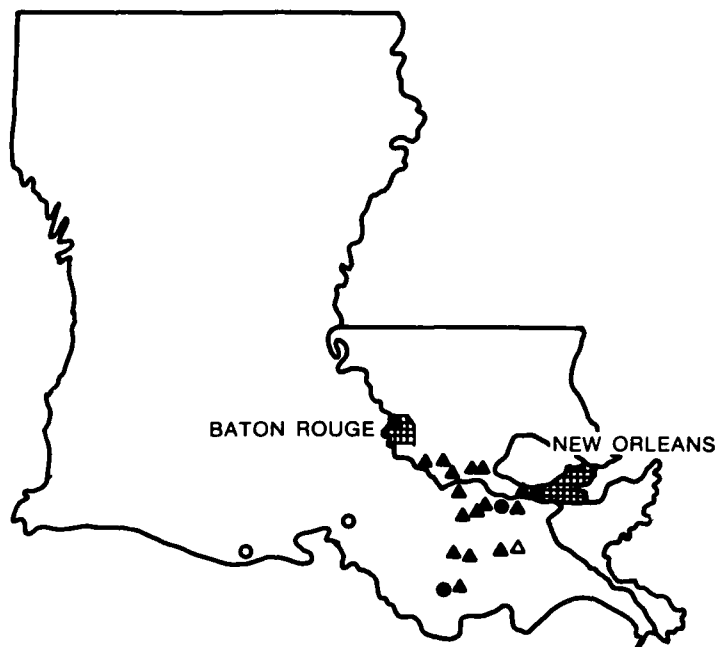


Figure 1. Populations of *S. albiguttalis* established in Louisiana by October 1981

the insect's instinctive drive to disperse following pupation. We will continue to monitor the sites as well as conduct a yearly survey to determine the spread.

Thus far it can be concluded that:

- a. *Sameodes albiguttalis* has become established in two of the four release sites.
- b. *Sameodes albiguttalis* has spread from the release sites and become established throughout southeastern Louisiana.

#### **Neochetina spp.**

The waterhyacinth weevils *Neochetina eichhorniae* and *N. bruchi* are exotic species introduced from Argentina for the control of waterhyacinth. The weevils were first released in Louisiana in 1974 and 1976, respectively, by the Louisiana Department of Wildlife and Fisheries. During a 4-year period from 1974-1977, further releases were made in the state and the insects were collected and spread from the nursery areas. When the LSOMT was initiated, the insects were well established. Therefore, it is considered a treatment in all large-scale studies and its population levels are monitored in all test sites.

***Neochetina* spp. population.** Since the beginning of the study, it has become increasingly obvious from the data taken at the field sites that there has been an

enormous buildup of the insects throughout south Louisiana. In fact, in August of 1980, a tremendous swarming of *Neochetina* spp. was recorded in southeast Louisiana. The Louisiana Department of Wildlife and Fisheries received calls from throughout the area stating that the insects were collecting in large numbers at school houses, in parking lots, and outside of restaurants and grocery stores. It was later confirmed that, in every instance, the site was in an area where a large population of waterhyacinth was present and the buildings used mercury vapor lamps for night lights. Both *Neochetina* spp. are attracted to mercury vapor lights. These reports are the first of their kind in the state and they confirm the buildup we have documented in the field.

**Waterhyacinth population.** When one looks at the total acreages of waterhyacinth in Louisiana, which was supplied by the Louisiana Department of Wildlife and Fisheries, one sees that a severe decline in the population of waterhyacinth has occurred (Figure 2). The decline coincides with the buildup of the insects. Although the control programs of the New Orleans District and Louisiana's Department of Wildlife and Fisheries and environmental conditions have had a large impact, we feel that the major cause of the decline is due mainly to the stress caused by the *Neochetina* spp. From the data we have collected in the

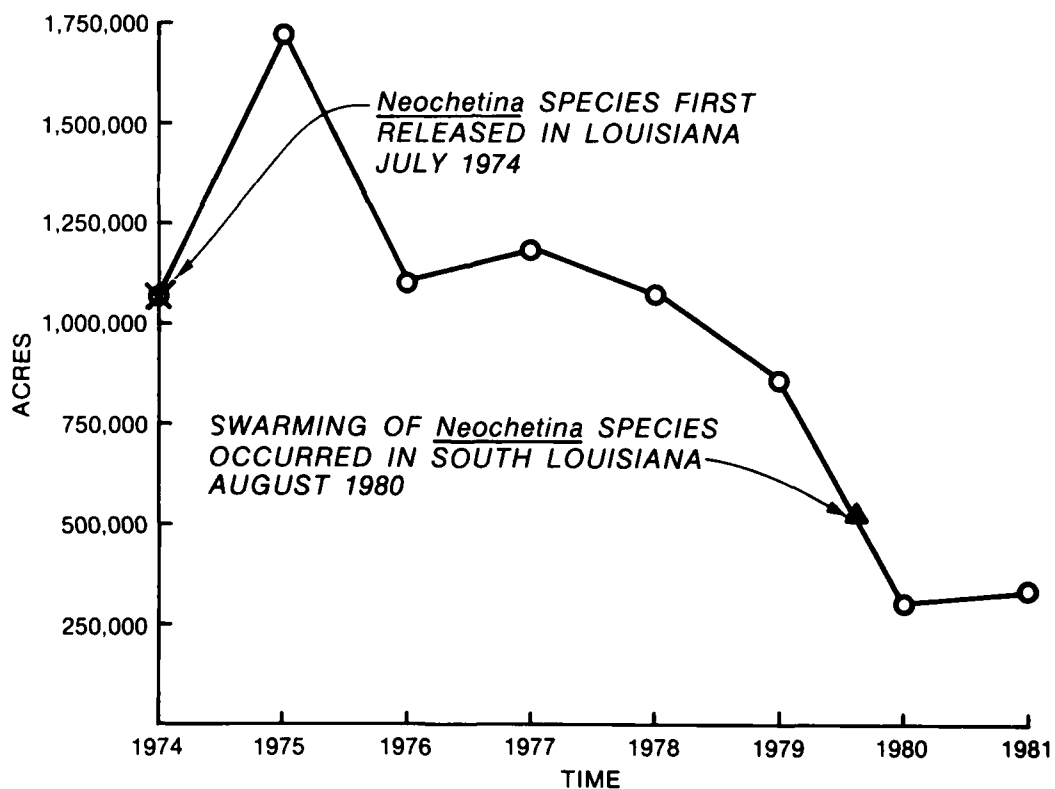


Figure 2. Population of waterhyacinth in Louisiana

field since April of 1979, we feel that we are nearing a predictive capability for control of waterhyacinth with *Neochetina* spp. at the present time. We will continue to monitor the large-scale sites for 2 more years to monitor the progress of the insects.

## SUMMARY

To summarize, I would like to list the achievements that have been accomplished thus far in the LSOMT-IP:

**a. *Cercospora rodmanii*.**

- (1) Abbott Laboratories formulation has been tested in the laboratory and found to be infectious on waterhyacinth.
- (2) Suitable application techniques have been developed for both ground-level and aerial application of the formulation.
- (3) The formulation of *C. rodmanii* has effected a significant reduction in biomass 2 years following a large-scale application.

**b. *Arzama densa*.**

A method of mass rearing of *Arzama* has been developed to place thousands of organisms in the field when needed.

**c. *Sameodes albiguttalis*.**

- (1) *Sameodes* has been released and established at two sites in south Louisiana.
- (2) The insects have spread from the original release site and are well established throughout southeast Louisiana.

**d. *Neochetina* spp.**

- (1) A phenomenal buildup of *Neochetina eichhorniae* and *N. bruchi* populations has been documented throughout south Louisiana.
- (2) A reduction of approximately 900,000 acres of waterhyacinth has occurred in Louisiana to coincide with the enormous buildup of *Neochetina* spp.
- (3) The elimination of two test sites has occurred during the study, which documents *Neochetina* spp. as the major cause of the reduction of waterhyacinth in Louisiana.

# **LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA**

## **An Overview**

by  
Andrew C. Miller\*

## **INTRODUCTION**

Since 1976, Lake Conway, near Orlando, Fla., has been the site of a Large-Scale Operations Management Test (LSOMT) on the use of the white amur or grass carp (*Ctenopharyngodon idella* Val.) as an aquatic macrophyte control agent. This study, funded by the U.S. Army Engineer District, Jacksonville, and the Office, Chief of Engineers, was designed (Decell 1976b) to satisfy three major objectives:

- a. Document the responses of various portions of a large ecosystem to the presence of the white amur.
- b. Provide the capability to extrapolate the results of this test to other aquatic ecosystems.
- c. Develop a basis for determining the feasibility of using the white amur on an operational scale

## **BACKGROUND**

Lake Conway consists of five interconnecting pools that vary in surface area ranging from 65.7 (Lake Gatlin) to 741 (Middle Pool) acres for a total surface area of 1833.28 acres. The pools range in depth from less than 7 m in Lake Gatlin to about 10 m in the Middle Pool (Nall and Schardt 1978). The five-pool lake system has only two major outlets. Water enters the lakes via runoff, direct precipitation, and underground seepage (Blancher and Fellows 1981). The lake shoreline can accurately be described as highly urbanized; the majority of the native vegetation around the periphery of the lake has been cleared for development of homes, docks, and beaches.

The Lake Conway system was stocked with white amur on 9 September 1977. The fish varied in weight from 0.25 to 0.61 kg and ranged from three per acre to five per acre. Approximately 7000 fish were released. The fish, purchased from the Fish Farming Experiment Station at Stuttgart, Ark., were monosex female to help ensure that reproduction would not occur. Three fish barriers (described by Theriot (1977) and Addor and Theriot (1977), were erected to prevent the white amur from escaping to other areas in Florida.

To fully meet the objectives of the project various physicochemical and

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\*U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

biological parameters were monitored for approximately 1 year prior to, and up to 4 years following, introduction of the amur. Baseline data included information gathered prior to 9 September 1977. The first poststocking year included data taken from September 1977 to September 1978. The second and third poststocking years contained data from September 1978 to September 1979, and September 1979 to September 1980, respectively. Selected studies have continued beyond the end of the third poststocking year. The final data collection work for this project will terminate in the spring of 1982.

An overview of the entire Lake Conway project, from its early planning stages and throughout much of the work, can be found in Decell (1976a, 1976b, 1977), and Addor and Theriot (1977). The majority of the contractor's reports have been or will be published by the U.S. Army Engineer Waterways Experiment Station (WES) and are cited in the list of references at the end of this paper. Summaries of the major findings of the contractor's studies appear in previous proceedings of Aquatic Plant Research Planning Conferences held in Seattle, Wash. (1978), Lake Eufaula, Okla. (1979), Savannah, Ga. (1980), and St. Paul, Minn. (1981). For more information contact Program Manager/Aquatic Plant Control Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 39180.

### SCOPE

It is the purpose of this paper to provide a brief summary of the results of the Lake Conway studies. At this time, the majority of the data have been collected, although detailed analyses have not been conducted. Selected contractor's reports on the effects of white amur introduction are completed; others have not been received. In the remaining time for this project, the following are major objectives:

- a. Complete a manual on use of the white amur as a biological control agent. This will provide background data on the fish, its effectiveness under various conditions, and methods for determining how many white amur are required to effect a specified level of control.
- b. Complete a final synthesis report on the results of the contracted biological, chemical, and physical studies conducted on the lake from 1976 to spring 1982. This document will include brief summaries of methods and materials, objectives, and results of each major study. In addition, it will synthesize major findings of the Lake Conway Project to provide a comprehensive view of the entire program.
- c. Compile the results of the study into well-organized, easily accessible data sets. Data will be stored permanently on magnetic tapes; individual or multiple data sets can be assessed from the WES IBM Computer for listings or statistical analyses using the Statistical Analysis System (SAS) program.

### ADDITIONAL FACTORS

Between the start of the study (about 1976) and its termination in 1982, the amount and quality of the terrestrial and aquatic habitat surrounding the lake

diminished. Williams (1980) reported that between 1970 and 1980 the resident population increased by 2305; roughly 200 new homes were built between 1975 and 1979. In addition, the fall of 1980 to the fall of 1981 was one of the driest periods on record. Large areas previously covered with water became exposed in late summer 1981. A connecting waterway between Lake Gatlin and the Middle Pool became so shallow and infested with cattails that boat traffic between the two pools became impossible. As a result, Lake Gatlin essentially became isolated from the rest of the system. It may not be possible to accurately assess these influences and precisely quantify their effect on the changes in the other physicochemical variables recorded throughout the poststocking years.

## RESULTS AND DISCUSSION

The following paragraphs briefly summarize the objectives and major findings of each of the studies conducted on the effects of using the white amur at Lake Conway, Florida. Smith and Shireman (1980) provide references pertaining to the use of the white amur in other lakes in Florida and in other states.

### Aquatic plants

The Florida Department of Natural Resources, Tallahassee, Fla. (Nall, Mahler, and Schardt 1977; Nall and Schardt 1978, 1980a, 1980b), monitored the percent frequency, standing crop, and species composition of the aquatic vascular plants in the Lake Conway system. In addition, they successfully implanted more than 25 white amur with radio transmitters and plotted their movements in relation to changes in vegetation cover through time. More detail on the method of radiotracking appears in Keown (1980). Nixon and Miller (1978) also studied movements of white amur using radiotelemetry.

At the start of the study, more than 12 species of aquatic plants grew in or along the edges of Lake Conway; the most common species were *Hydrilla*, *Vallisneria*, *Nitella*, and *Potamogeton*. Other species in lesser quantities were *Najas* and *Cabomba*. Prior to introduction of the fish, approximately one half of the lake's surface contained fairly high levels of the four major species of plants. The plants were found in both shallow and deep waters, were most abundant in the Middle Pool, and were virtually absent from Lake Gatlin. The white amur slowed the rate of increase of plant growth within 1 year of introduction. By the end of poststocking year II, total plants in the system had declined notably. Based on radiotracking studies, the white amur fed preferentially in the deeper areas of the lake, then moved to the shallower areas when the deeper waters were vegetation-free. By the end of 1980, total plant growth had been reduced about 75 percent in the lake. At this time, the quantities of vegetation consumed by the white amur in the lake began to decline. This was partially the result of mortality and reduced food consumption rates of older fish. By late summer 1981, it was noted that *Hydrilla*, *Vallisneria*, and other aquatic macrophytes were beginning to increase slightly throughout the lake system.

### **Recording fathometer**

The School of Forest Resources, University of Florida, Gainesville, investigated the use of a recording fathometer to measure percent cover, vertical height, and biomass of hydrilla in a body of water. The purpose of this work was to develop a rapid and inexpensive technique for accessing plant infestations. Information on coverage, biomass, etc., of plants in a lake is needed to plan and execute a vegetation control program.

In the Maceina and Shireman (1980) procedure, a single operator in a small boat with a fathometer makes a series of transects across beds of vegetation. The resulting trace must be interpreted by taking selected grab samples in the plant bed. Any unusual or difficult to interpret tracings are marked with a plastic jug and weight and evaluated after the transect is made. This technique is less expensive and more time effective than using a diver or a biomass sampler.

### **Plankton, benthos, and periphyton**

The University of Florida Department of Engineering Sciences (Crisman and Kooijman 1980) monitored numbers and community structure of plankton, benthos, and periphyton before and after introduction of the white amur in Lake Conway. Benthic grabs and quantitative plankton hauls from a series of deep and shallow water stations were conducted monthly at sites located in all five pools.

Introduction of the white amur and subsequent plant removal affected numbers of blue-green algae in the lake. Prior to stocking, the blue-green algae exhibited a fairly typical summer maximum and winter minimum. The Lake Conway system had been classified as mesotrophic in the baseline year; algal levels were high in the warmer months although water chemistry and plankton did not exhibit conditions characteristic of nutrient-rich or eutrophic conditions. After stocking, the seasonality of blue-greens was lost; total numbers increased and remained dominant all year. This condition existed during poststocking years I, II, and III; however, conditions appeared to be reversing at the termination of the study. At this time, the blue-greens began to exhibit seasonality and total numbers decreased.

Stocking white amur appeared to have little or no effect on numbers or diversity of benthic invertebrates (mainly aquatic insects and snails) or zooplankton. Blue-green algae are not a preferred food item of many zooplankters; the lack of impact to these predatory organisms is confirmed by other research (Fry and Osborne 1980).

### **Water and sediment chemistry**

Water and sediment samples were taken using standard Kemmer and Ponar grab samplers, respectively, by the Orange County Pollution Control Board (Kaleel 1980). Samples were obtained monthly at selected stations in all pools. The water was analyzed for major cations, anions, pH, specific conductance, color, dissolved and suspended solids, and biological and chemical oxygen demand. Levels of iron,

phosphorus, manganese, lead, nitrogen, copper, and chemical oxygen demand were monitored for each sediment sample.

In the water column, no major chemical changes were observed as a result of stocking the white amur. It was reported that filterable and unfilterable phosphorus decreased slightly while carotenoids, chlorophyll-a, and ammonia concentrations increased. In addition, it was noted that major water chemistry differences among the pools diminished during the study period. In the baseline period, Lake Gatlin had substantially higher levels of phosphorus, nitrate nitrogen, and diminished oxygen when compared with the other four pools. By poststocking year III, these differences had been ameliorated; nutrient levels in the other four pools had increased slightly. Whether this was the result of white amur introduction or other associated factors has not been resolved. However, the observed trends, i.e., slight increases in certain nutrients following introduction of white amur and plant removal, have been noted in other studies (Mitzner 1978). However, it must be pointed out that the Lake Conway system developed no objectionable color or odor problems and produced no visible planktonic "blooms" as a result of fish introduction. Michewicz, Sutton, and Blackburn (1972) reported that phosphorus levels in water in plastic tanks was not affected by plant removal by white amur although nutrient levels following herbicide application in similar sized plastic tanks increased. Presumably, the fecal pellets produced by the white amur did not decompose as quickly as the plants sprayed with herbicide; likewise, the phosphorus in the fecal material was not readily available for biological activity.

#### **Fish, waterfowl, and aquatic mammals**

An assessment of community structure and numbers of native fish, waterfowl, and aquatic mammals was provided by the Florida Game and Fresh Water Fish Commission (Guillory, Land, and Gasaway 1977; Guillory 1979). Observations on wintering waterfowl populations were made and compared with the state-wide census figures. Fish were collected by Weggner rings, block nets, seines, and electrofishing gear. Fish were identified and counted, and their reproductive status and condition factor (a comparison of breadth to length) were determined.

The white amur did not directly affect native fish populations during this study. However, the robustness (breadth compared to length) of the larger sized largemouth bass increased followed by a decrease in numbers and robustness of the smaller bluegill and other prey fish. Evidently, the removal of the aquatic vegetation decreased hiding places and food items (crustaceans and other plankton) for small fish. The larger sized bass were able to successfully exploit this resource. In addition, angler success, as measured with creel census, increased following stocking. This was undoubtedly the result of enhanced fisherman interest and fishing pressure as the lake surface was cleared of vegetation.

Numbers of waterfowl which feed upon aquatic plants (American coot, ring-necked duck) declined throughout the poststocking years. This decline, an accurate reflection of state-wide trends, could have been caused by prevailing meteorologic

conditions or water level fluctuations in the lake. The aquatic mammals censused during the period experienced a similar decline. This was certainly the result of habitat clearing for residential development along the periphery of the Lake Conway system.

### **Reptiles and amphibians**

The University of South Florida, Tampa (Godley, McDiarmid, and Bancroft 1981), evaluated numbers, community structure, and feeding habitats of amphibians and reptiles of the Lake Conway system following introduction of white amur. They either implanted or attached a small radio transmitter to selected species (the giant salamander, *Amphiuma*, and several species of turtles). Data were collected by tending live traps, making counts of live individuals spotted or heard during night surveys, and following movements of the radio-tagged individuals. These data will be used to provide detailed information on overall community structure and natural history (Godley 1980) of selected species.

The herbivorous turtles restricted their movements principally to vegetated areas. When aquatic plants declined during the poststocking year, these individuals became more concentrated. Certain species of turtles, snakes, and amphibians declined in numbers throughout the study period. This was probably related to construction along the lake shores and a decrease in water levels.

### **Models**

Two computerized models were developed as part of the Lake Conway project. The first was an ecosystem simulation model (Ewel and Fontaine 1975, 1977, 1980) designed by the University of Florida at Gainesville. The purpose of their work was to quantify and partition the various flows of energy through the trophic levels of the existing biotic communities. Information developed would aid in the interpretation of the baseline and poststocking data. In a related study, Blancher and Fellows (1981) discussed nitrogen and phosphorus dynamics of the Lake Conway system. A second model (Schramm 1979) was a set of algorithms relating hydrilla growth rates and vegetation removal rates to water temperatures, season of the year, and carrying capacity of the lake for *Hydrilla*. This stocking rate model is a tool to assist in determining how many fish will be required to achieve a certain level of vegetation control, depending upon various external conditions.

## **SUMMARY**

Lake Conway, near Orlando, Fla., has been the site of a Large-Scale Operations Management Test on the use of the white amur to control nuisance levels of aquatic vegetation. Data on sediment and water chemistry, plankton, periphyton, benthos, reptiles, amphibians, native fish, aquatic mammals, waterfowl, and aquatic plant distribution have been collected in a baseline year (before September 1977) and for up to three or more poststocking years (1977-1982). In addition, data on movements of the white amur and certain reptiles and amphibians have been examined using radiotelemetry. Two computerized models have been developed, one to assist in

predicting white amur stocking rates, and the other to quantify energy flows between the various trophic levels at Lake Conway. A technique for using a recording fathometer has been discovered that measures height, percent cover, and biomass of *Hydrilla* in a water body.

During the study period, the Lake Conway shoreline was dramatically changed by clearing and residential development. In addition, 1980 and 1981 were extremely dry years; water levels dropped, exposing previously water-covered areas, and the interconnecting lakes became more isolated from one another. These associated factors may make interpretation of some of the collected data difficult.

The white amur successfully controlled nuisance levels of aquatic vegetation within 2 years. There were no major detrimental impacts to any of the native vertebrates or invertebrates in this system. As a result of macrophyte removal, blue-green algae lost their seasonal dominance and increased in numbers, and larger sized largemouth bass preyed more successfully on small fish and increased in robustness. In addition, angler success increased following removal of aquatic plants.

## REFERENCES

- Addor, E. E., and Theriot, R. F. 1977. "Test Plan for the Large-Scale Operations Management Test of the Use of the White Amur to Control Aquatic Plants," Instruction Report A-77-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Blancher, E. C., and Fellows, C. R. 1981. "Nitrogen and Phosphorus Dynamics of the Lake Conway Ecosystem: Loading Budgets and a Dynamic Hydrologic Phosphorus Model" in preparation, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Crisman, T. L., and Kooijman, F. M. 1980. "Benthos," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 298-304.
- Decell, J. L. 1976a. "Large-Scale Field Test with the Monosex White Amur in Florida," *Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 22-24 October 1975, Charleston, S.C.*, Miscellaneous Paper A-76-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. pp 112-126.
- Decell, J. L. 1976b. "National Briefing on the White Amur Research Project, Lake Conway, Florida," U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Decell, J. L. 1977. "Overview of the U.S. Army Corps of Engineers Aquatic Plant Control Research Program," *Proceedings, Research Planning Conference on Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla.*, Miscellaneous Paper A-77-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 8-15.

- Ewel, K. C., and Fontaine, T. D. 1975. "Possible Effects of the Introduction of the White Amur into Lake Conway, Florida," *Proceedings of the Research Planning Conference of the Aquatic Control Program, 22-24 October 1975, Charleston, S.C.*, Miscellaneous Paper A-76-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 64-84.
- Ewel, K. C., and Fontaine, T. D. 1977. "Proposed Relationships Between White Amur and the Aquatic Ecosystem at Lake Conway Florida," *Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla.*, Miscellaneous Paper A-77-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 159-176.
- Ewel, K. C., and Fontaine, T. D. 1980. "Ecosystem Modeling of the Effects White Amur Grazing on Energy Flows," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 315-329.
- Fry, D. L., and Osborne, J. A. 1980. "Zooplankton Abundance and Diversity in Central Florida Grass Carp Ponds," *Hydrobiologia*, Vol 68, No. 2, pp 145-155.
- Godley, J. S. 1980. "Foraging Ecology of the Striped Swamp Snake, *Regina alleni*, in Southern Florida," *Ecological Monographs*, Vol 50, No. 4, pp 411-436.
- Godley, J. S., McDiarmid, R. W., and Bancroft, G. T. 1981. "Large-Scale Operations Management Test of Use of the White Amur for Control of Problem Aquatic Plants; Report 1, Baseline Studies; Vol V: Herpetofauna of Lake Conway, Florida," Technical Report A-78-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Guillory, V., Land, R., and Gasaway, R. 1977. "Baseline Data Report — Lake Conway Grass Carp Project," *Proceedings, Research Planning Conference on Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla.*, Miscellaneous Paper A-77-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 97-112.
- Guillory, V. 1979. "Large-Scale Operations Management Test of Use of the White Amur for Control of Problem Aquatic Plants; Report 1, Baseline Studies; Volume II: The Fish, Mammals, and Waterfowl of Lake Conway, Florida," Technical Report A-78-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Kaleel, R. T. 1980. "Water Quality," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 285-297.
- Keown, M. P. 1980. "Radiotelemetry Tracking of White Amur," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Station, CE, Vicksburg, Miss., pp 330-335.
- Maceina, M. J., and Shireman, J. V. 1980. "Use of a Recording Fathometer for Determining Distribution and Biomass of Hydrilla," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Program Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 370-383.

- Michewicz, J. E., Sutton, D. L., and Blackburn R. D. 1972. "Water Quality of Small Enclosures Stocked with White Amur," *Hyacinth Control Journal*, Vol 10, pp 22-25.
- Mitzner, L. 1978. "Elevation of Biological Control of Nuisance Aquatic Vegetation by Grass Carp," *Transactions of the American Fisheries Society*, Vol 107, No. 1, pp 135-145.
- Nall, L. E., Mahler, M. J., and Schardt, J. D. 1977. "Aquatic Macrophyte Sampling in Lake Conway," *Proceedings, Research Planning Conference on Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla.*, Miscellaneous Paper A-77-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 113-122.
- Nall, L. E., and Schardt, J. D. 1978. "Large-Scale Operations Management Test of Use of the White Amur for Control of Problem Aquatic Plants; Report 1, Baseline Studies; Vol I: The Aquatic Macrophytes of Lake Conway, Florida," Technical Report A-78-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Nall, L. E., and Schardt, J. D. 1980a. "Aquatic Macrophytes," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 249-272.
- Nall, L. E., and Schardt, J. D. 1980b. "Procedure for Radio Tagging of White Amur for Tracking Studies," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 336-362.
- Nixon, D. E., and Miller, R. L. 1978. "Movements of Grass Carp, *Ctenopharyngodon idella*, in an Open Reservoir System as Determined by Underwater Telemetry," *Transactions of the American Fisheries Society*, Vol 107, No. 1, pp 146-148.
- Schramm, H. L. 1979. "White Amur Stocking-Rate Model," The Warm Water Workshop, American Fisheries Society, Northeastern Division, 14-16 October 1979.
- Smith, C. R., and Shireman, J. V. 1981. "Grass Carp Bibliography," University of Florida, Institute of Food and Agricultural Sciences, Center for Aquatic Weeds, Gainesville, Fla.
- Theriot, R. F. 1977. "Large-Scale Operations Management Test (LSOMT) With the White Amur at Lake Conway, Orlando, Florida," *Proceedings, Research Planning Conference on Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla.*, Miscellaneous Paper A-77-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 87-96.
- Williams, R. R. 1980. "Human Factors Study," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 363-369.

# LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR IN LAKE CONWAY, FLORIDA

## Aquatic Macrophytes

by

Jeffrey D. Schardt,\* Larry E. Nall,\* and Gregory P. Jubinsky\*

Lake Conway, as most central Florida lakes, suffered from the continuing drought plaguing the Southeast during 1980 and 1981. The water level decreased by nearly 1.5 m during the fifth study year, rendering most of the boat houses and boat docks useless. Radiotelemetry studies of the white amur in Lake Conway showed that the amur were found in 3 m of water or less nearly 90 percent of the time feeding in areas predominantly covered by *Nitella* or *Potamogeton*.\*\* Control achieved by the fish is difficult to separate from control due to the natural drawdown since both *Potamogeton* and *Nitella* standing crops were significantly reduced in the fifth study year, but only in water shallower than 4.0 m. The water level was fairly constant during the first 3 years after the fish were stocked; therefore the vegetation changes during that time can be attributed to the amur.

## METHODS AND MATERIALS

Aquatic vegetation was collected for 5 years from Lake Conway, including one full year of baseline data prior to the release of the white amur. The 4 years of data collected after stocking will be referred to herein as poststocking years and designated as PS1, PS2, PS3, and PS4, respectively. Four major aquatic plant species were present in Lake Conway at the beginning of the study (Table 1). *Hydrilla verticillata*, *Potamogeton illinoensis*, and *Nitella megacarpa* were all preferred by the white amur and *Vallisneria americana* which was nonpreferred. Sampling methods are described in the baseline report.† This report will serve as an update and will only cover representative examples of major trends occurring in the lake through PS4.

## RESULTS

### Total vegetation

Transects and random samples showed that total vegetation, percent frequency and standing crops, increased in Lake Conway during the baseline year, through

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\* Florida Department of Natural Resources, Tallahassee, Florida.

\*\* See paper by Schardt, Jubinsky, and Nall beginning on page 235 of this proceedings.

† Nall, L. E., and Schardt, J. D. 1978. "Large-Scale Operations Management Test of Use of the White Amur for Control of Problem Aquatic Plants; Report 1, Baseline Studies; Volume I: The Aquatic Macrophytes of Lake Conway, Florida," Technical Report A-78-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table 1  
Approximate Feeding Preferences of the White Amur\*

<b>Greatly prefers:</b>	
<i>Nitella</i> and <i>Chara</i> spp.	
<i>Hydrilla verticillata</i>	
<i>Najas</i> spp.	
<i>Potamogeton</i> spp.	
Duckweeds ( <i>Lemna</i> , <i>Spirodella</i> , <i>Wolffia</i> , <i>Wolffiella</i> , <i>Azolla</i> )	
<i>Ceratophyllum demersum</i>	
<i>Eleocharis acicularis</i>	
<i>Elodea canaensis</i>	
<i>Pithophora</i> sp.	
<b>Will control but does not prefer:</b>	<b>Will not control effectively:</b>
<i>Myriophyllum</i> spp.	<i>Vallisneria</i> spp.
<i>Bacopa</i> spp.	<i>Typha</i> spp.
<i>Egeria densa</i>	<i>Myriophyllum brasiliense</i>
<i>Nymphaea</i> spp.	<i>Phragmites</i> spp.
<i>Polygonum</i> spp.	<i>Carex</i> spp.
<i>Spirogyra</i> sp.	<i>Scirpus</i> spp.
<i>Utricularia</i> spp.	<i>Eichhornia crassipes</i>
<i>Cabomba</i> spp.	<i>Alternanthera philoxeroides</i>
<i>Fuirena scirpoides</i>	<i>Pistia stratiotes</i>
<i>Brasenia schreberi</i>	<i>Nymphoides</i> spp.
<i>Hydrocotyle</i> spp.	<i>Nuphar macrophyllum</i>

\* Only those species common to Florida are listed.

PS1, to reach maximum levels early in PS2. The greatest effect by the white amur occurred during PS2 and in water shallower than 4.0 m. Total vegetation did not recover after the normal winter die-off during the first half of PS2 and standing crops remained significantly below late PS2 levels for the duration of the study in depths less than 4.0 m.

The decline in South Pool total vegetation frequency ended in PS3 and values remained constant during PS4 (Figure 1). Standing crop began to increase in PS3 and continued during PS4 (Figure 2). Standing crop averaged 840 g/m<sup>2</sup> in PS4; this was an increase of 315 g/m<sup>2</sup> from the previous year (Table 2).

East Pool total vegetation frequency and standing crop decreased during each poststocking year. Average frequency and standing crops were 39 percent and 229 g/m<sup>2</sup> in PS4 compared to the maximum annual averages of 63 percent and 1501 g/m<sup>2</sup> recorded in PS2 and PS1, respectively (Table 2). Most of the East Pool vegetation loss during PS4 was attributable to the loss of water as almost 20 percent of the vegetated lake bottom was exposed (30 percent of the transect points nearly went dry).

West Pool total vegetation frequency and standing crop increased in PS4 to an average of 34 percent and 601 g/m<sup>2</sup> after minimum averages of 29 percent and 304 g/m<sup>2</sup> were recorded in PS3 (Table 2).

### Hydrilla

Although *Hydrilla*, the target species of the study, was not a nuisance in Lake Conway when the project was initiated, all sampling methods showed that South,

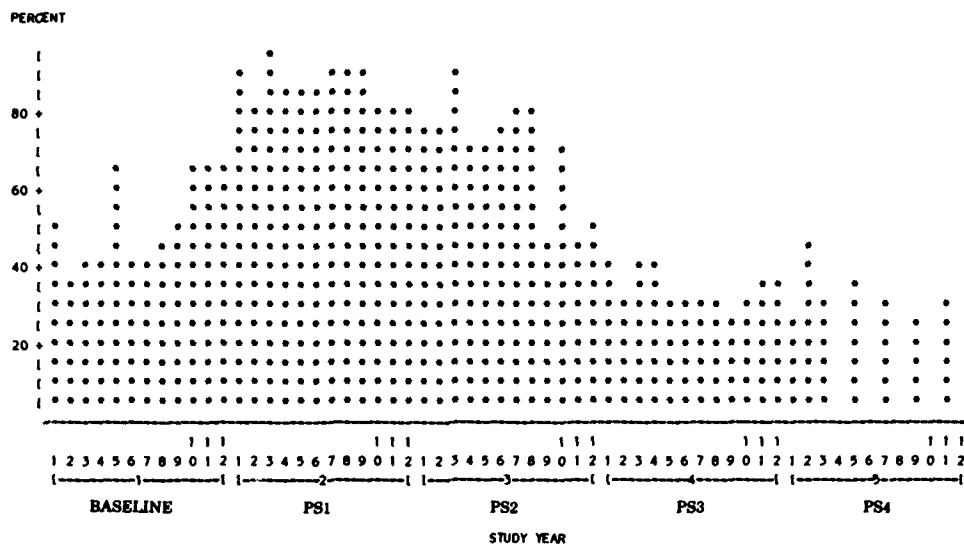


Figure 1. Total vegetation frequency in South Pool

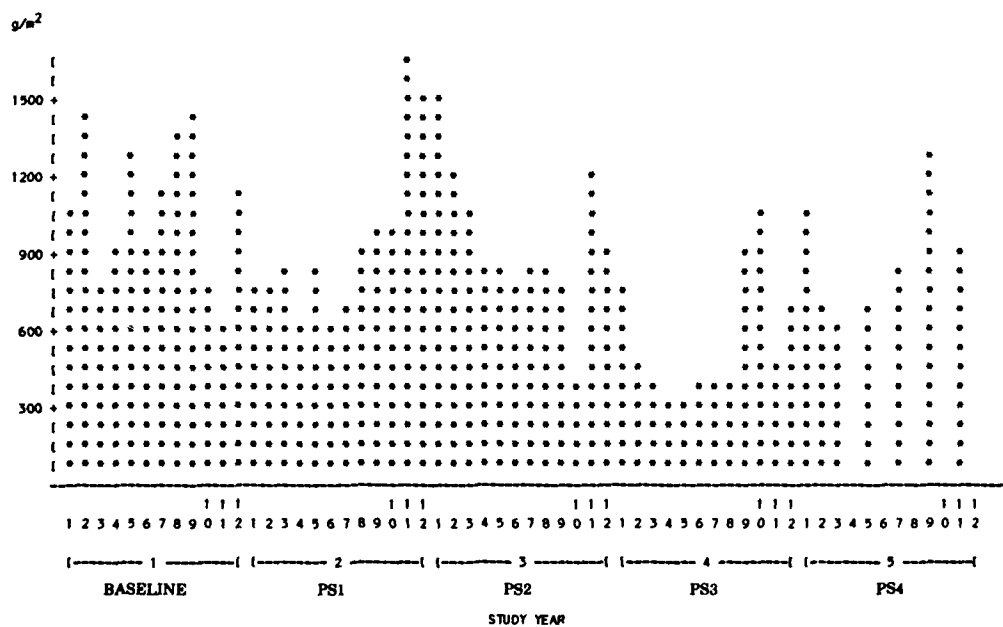


Figure 2. Total vegetation standing crop in South Pool

**Table 2**  
**Table of Percent and Standing Crop by Species, Pool and Study Year**

	<i>Pool</i>	<i>South</i>		<i>Middle</i>		<i>East</i>		<i>West</i>	
	Study Year	%	g/m <sup>2</sup>	%	g/m <sup>2</sup>	%	g/m <sup>2</sup>	%	g/m <sup>2</sup>
<b>Total Vegetation</b>	Baseline	50	1,059	50	1,769	57	1,501	46	1,046
	PS1	86	988	55	1,430	63	1,192	62	1,216
	PS2	70	923	55	1,197	55	734	39	591
	PS3	33	525	49	967	47	328	29	304
	PS4	31	840	47	1,125	39	229	34	601
<b>Hydrilla</b>	Baseline	24	344	2	16	14	188	26	719
	PS1	59	517	1	1	14	191	42	932
	PS2	36	216	0	0	9	34	18	756
	PS3	0	0	0	0	1	2	0	0
	PS4	0	0	0	0	4	52	0	0
<b>Potamogeton</b>	Baseline	20	296	24	294	37	512	23	337
	PS1	22	422	24	259	45	510	28	264
	PS2	21	228	18	96	34	205	16	57
	PS3	4	11	12	60	18	40	3	8
	PS4	3	11	12	81	11	51	5	19
<b>Nitella</b>	Baseline	19	1,824	34	2,385	24	1,929	12	1,721
	PS1	29	1,246	43	1,794	43	1,578	20	1,362
	PS2	36	1,258	43	1,491	33	889	15	626
	PS3	25	713	40	1,239	27	295	12	199
	PS4	26	1,020	40	1,283	17	190	16	786
<b>Vallisneria</b>	Baseline	7	550	2	240	27	531	7	232
	PS1	7	498	1	44	23	331	11	342
	PS2	8	754	1	10	27	221	14	83
	PS3	5	42	3	30	33	193	25	264
	PS4	4	64	2	10	33	150	26	199

East, and West Pool populations were increasing in the baseline year and PS1. Frequency and standing crop reductions began in the first half of PS2, and *Hydrilla* was nearly eliminated by the end of the year. *Hydrilla* frequency along South Pool transects was as high as 70 percent during PS1 (Figure 3). The maximum poststocking standing crop (over 800 g/m<sup>2</sup>) was recorded near the end of PS1 but *Hydrilla* was eliminated before the end of PS2 (Figure 4). *Hydrilla* was not found in the random samples during PS3.

West Pool transect data showed the same increase in frequency and standing crop through PS1, rapid decline in PS2, and elimination in PS3 (Figures 5 and 6). Maximum frequency and standing crop were 55 percent and 1700 g/m<sup>2</sup>, both in PS2.

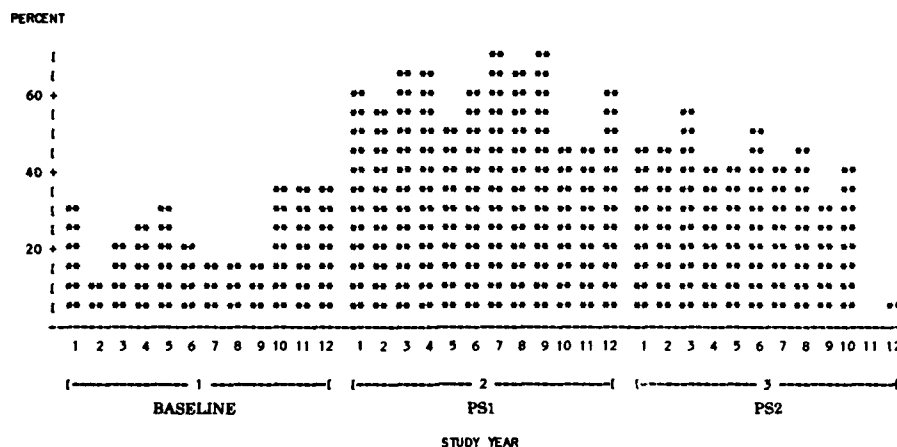


Figure 3. *Hydrilla* frequency in South Pool

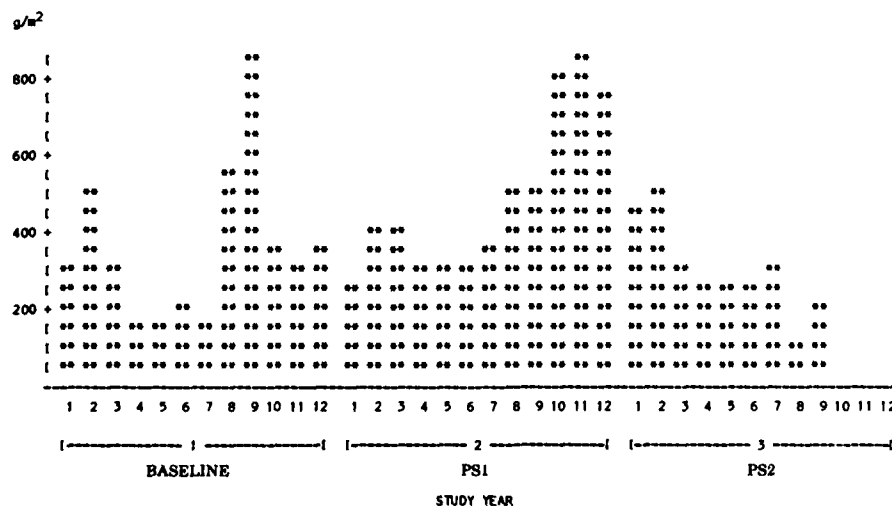


Figure 4. *Hydrilla* standing crop in South Pool

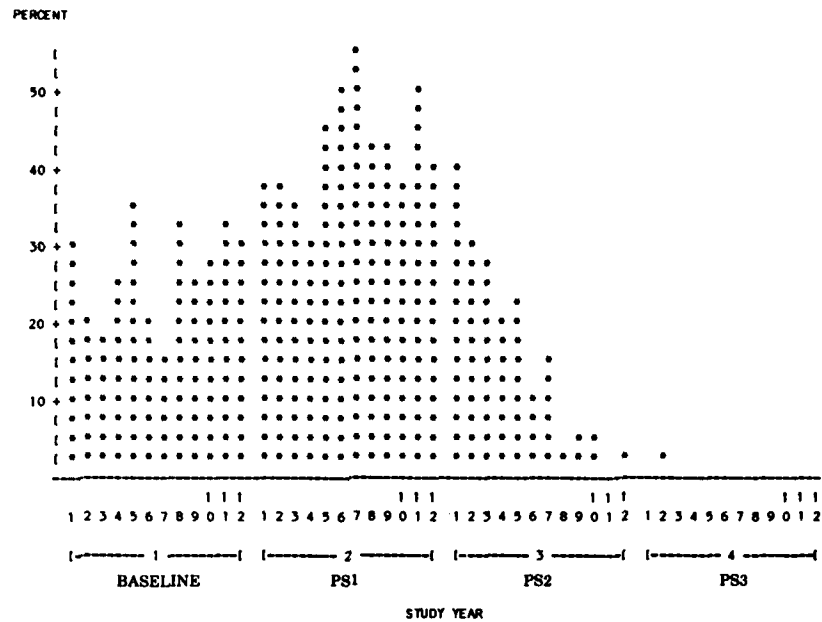


Figure 5. *Hydrilla* frequency in West Pool

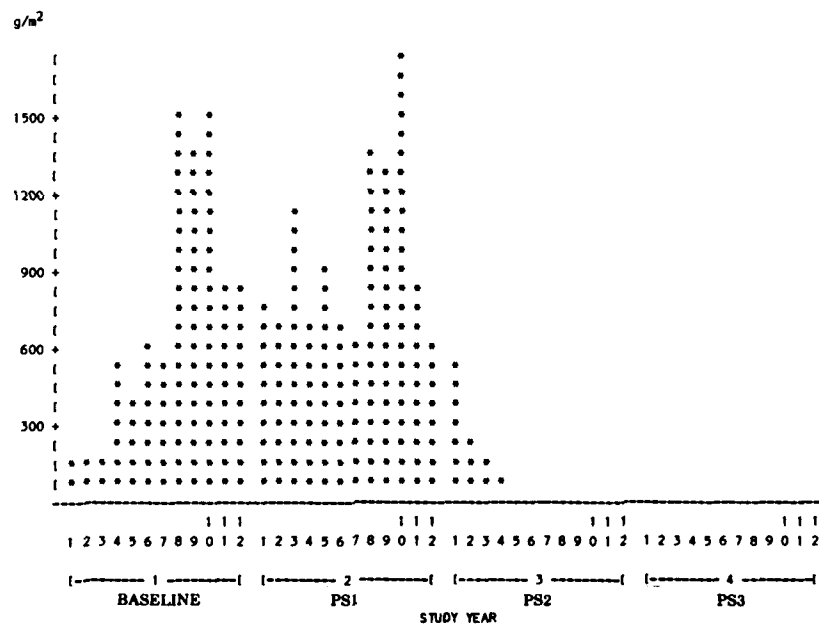


Figure 6. *Hydrilla* standing crop in West Pool

The East Pool *Hydrilla* population was smaller averaging 14 percent frequency and a 191-g/m<sup>2</sup> standing crop in PS1 (Table 2), but decreased at the same rate and time as in South and West Pools. *Hydrilla* was not eliminated from the East Pool transects.

## Potamogeton

*Potamogeton* was slightly less preferred and therefore not affected to the same extent as *Hydrilla* until late in PS1. South Pool *Potamogeton*, as in all Conway pools, began to decline early in PS2 after *Hydrilla* had been greatly reduced (Figures 7 and 8). *Potamogeton* frequency was reduced to a few percentage points in all pools by the end of PS3. The decline in frequency and standing crop during PS2 and the low levels in PS3 were in response to white amur grazing; however, any continued low levels in PS4 may have resulted from the low water. *Potamogeton*'s optimal growth in Lake Conway occurred between 0.5 and 3.0 m.\*

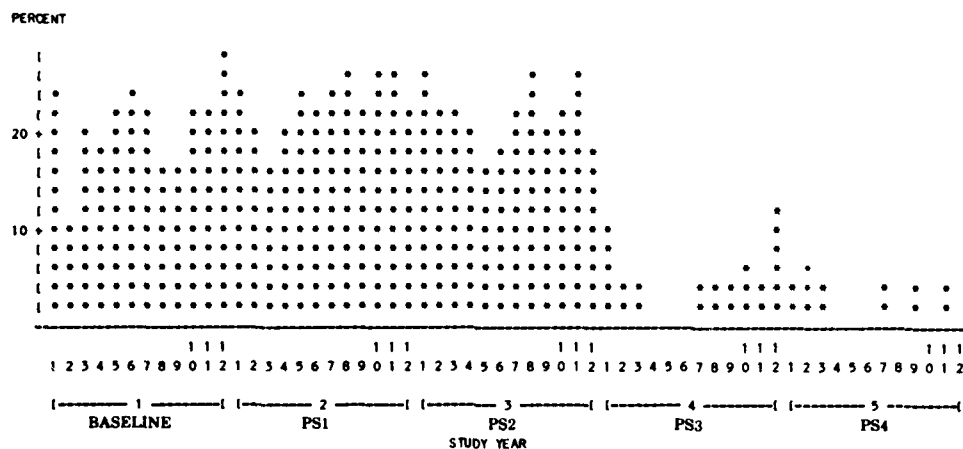


Figure 7. *Potamogeton* frequency in South Pool

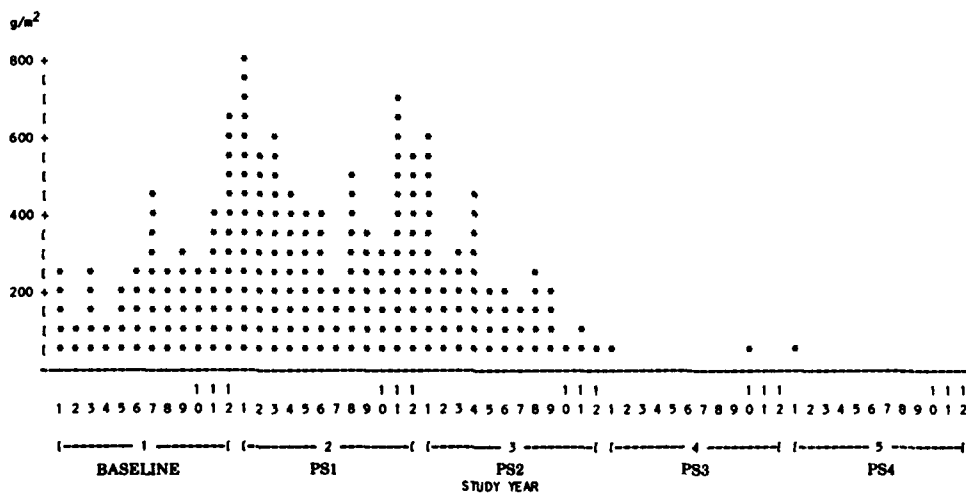


Figure 8. *Potamogeton* standing crop in South Pool

\* Nall and Schardt (1978).

*Nitella* frequency increased along transects in all pools in the baseline year and PS1. Despite reductions in all pools during PS2, average frequency dropped below baseline levels only in East Pool (Table 2, Figure 9). Average standing crops decreased during PS1 and PS2, but significant ( $P>0.01$ ) reductions did not occur until PS3 (Table 2). Maximum standing crops were recorded in the fall of PS1 (Figure 10). *Nitella* was significantly reduced by the following spring in water shallower than 4.0 m, but significant reductions did not occur in deeper water until



the following year. *Nitella* standing crops stabilized throughout Lake Conway in PS3 and increased in PS4 (Figure 10) except in the areas of East Pool that were affected by low water.

Middle Pool *Nitella*, which grew predominately in water deeper than 4.0 m, increased in frequency from a baseline average of 34 to 43 percent in PS1, then remained nearly constant for the duration of the study (Table 2). Standing crop was significantly reduced below the baseline level early in PS2, but remained statistically the same for the remainder of the study.

West Pool *Nitella* was significantly reduced in PS3 but increased in frequency and standing crop in PS4 (Figures 11 and 12 and Table 2).

### **Vallisneria**

*Vallisneria* populations in South and Middle Pools were small throughout the study averaging less than 10 percent frequency at underwater inspection plots and along transects. Frequency increased along transects and at six of seven plots in East and West Pools during each of the five study years. The vegetation map (Figure 13) shows an increase in *Vallisneria* coverage from 15 to 40 percent in East Pool and from 9 to 17 percent in West Pool between the baseline year and PS3. *Vallisneria* was able to colonize the shallow waters of East and West Pools up to a depth of 3.0 to 3.5 m as *Hydrilla* and *Potamogeton* were removed by the amur.

Transect standing crops decreased each year in East Pool from an average of 531 g/m<sup>2</sup> in the baseline year to 150 g/m<sup>2</sup> in PS4, although only a slight difference was recorded between PS2 and PS4 (Table 2).

### **Plots**

Plot samples (Figures 14-16) show results similar to transects but in greater detail. Plot No. 1 (Figure 14) in South Pool, had a 100 percent *Nitella* coverage and a small *Hydrilla* population (24 percent) in the baseline year. *Hydrilla* declined midway through PS1 and was eliminated by the end of PS2. *Nitella* began to decline immediately after *Hydrilla* disappeared. Four months into PS3 no *Nitella* was found. Only isolated stems were found during PS4.

Plot No. 7 (Figure 15), in East Pool, had a 25 percent *Hydrilla* frequency when first sampled in the baseline year. *Hydrilla* completely covered the plot by the beginning of PS1. Stem densities and heights at the fixed measuring stations increased to their maximum values of 1909 stems/m<sup>2</sup> and 1.3 m, respectively, in the ninth month of PS1, but declined immediately afterwards until trace values were reached at the end of PS2. Frequency also declined during this period; however, although *Hydrilla* became sparse, it did not disappear. *Vallisneria* was able to colonize Plot No. 7 while *Hydrilla* was at low levels. Both species reached frequencies near 100 percent at the end of the study; however, densities remained very low.

Plot No. 10 (Figure 16), in West Pool, illustrates the same important point demonstrated by West Pool transects. *Hydrilla* was the dominant plant for the



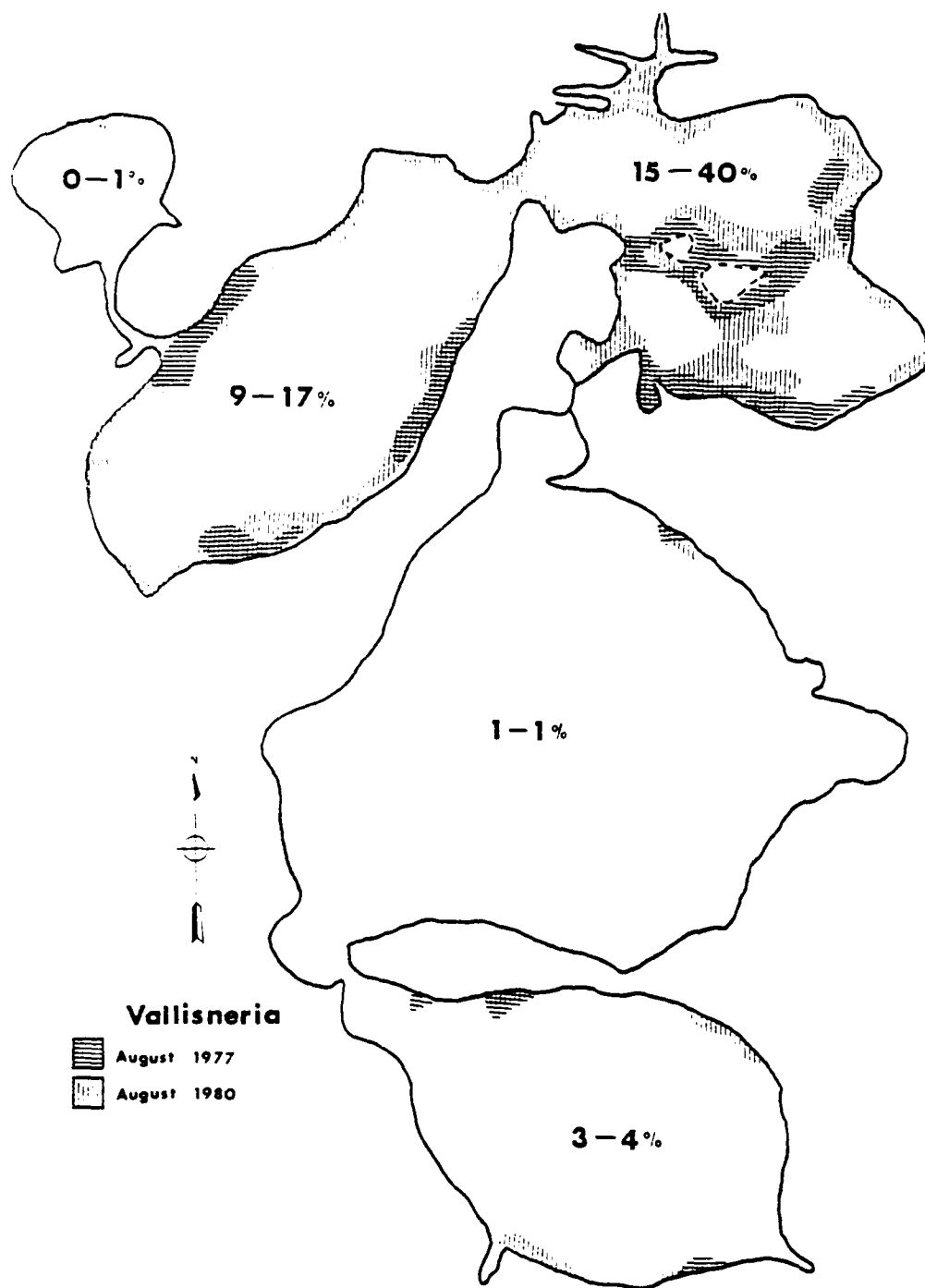


Figure 13. Increase in *Vallisneria* percent coverage, PS3

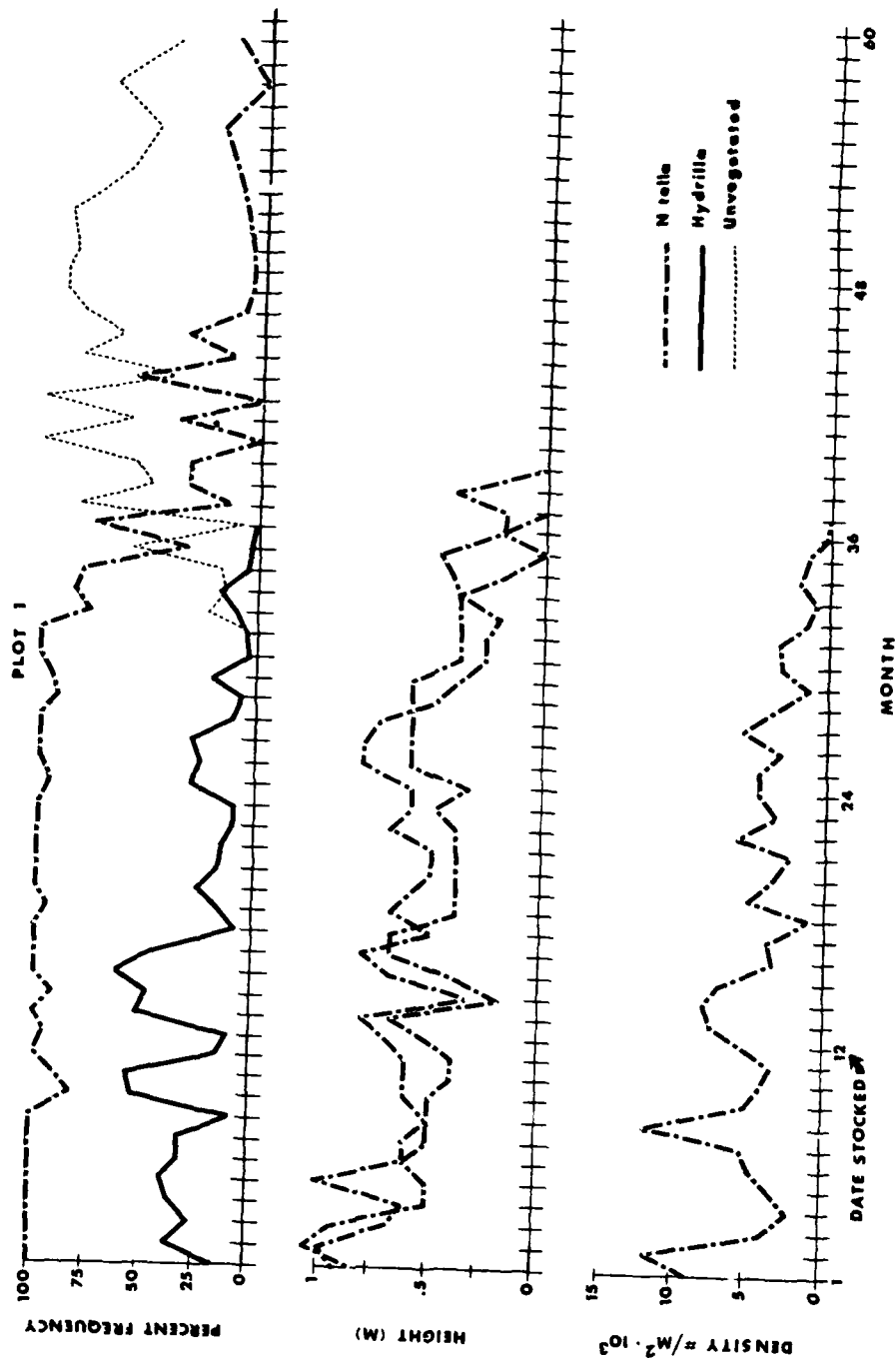


Figure 14. South Pool plot sample

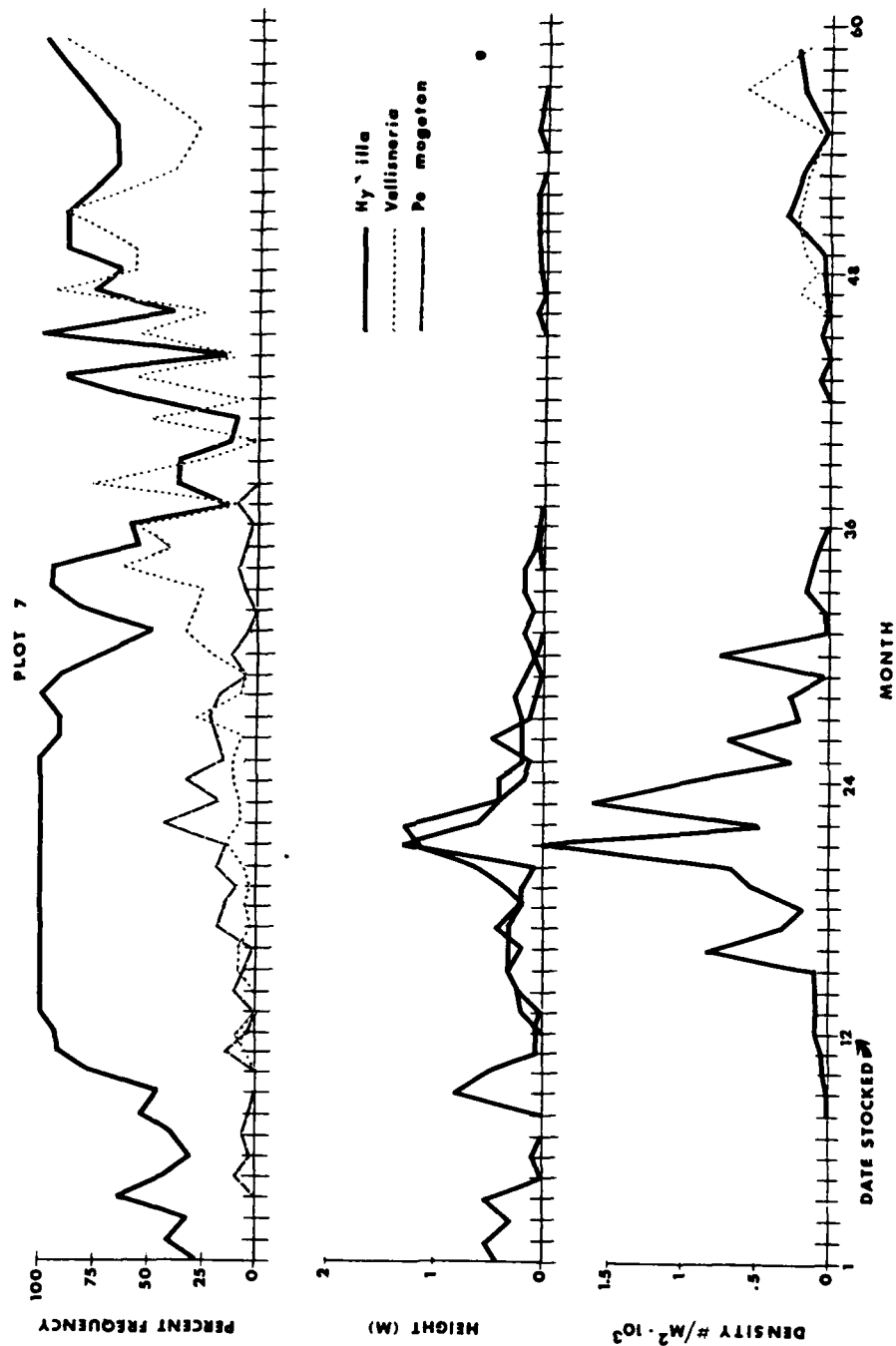


Figure 15. East Pool plot sample

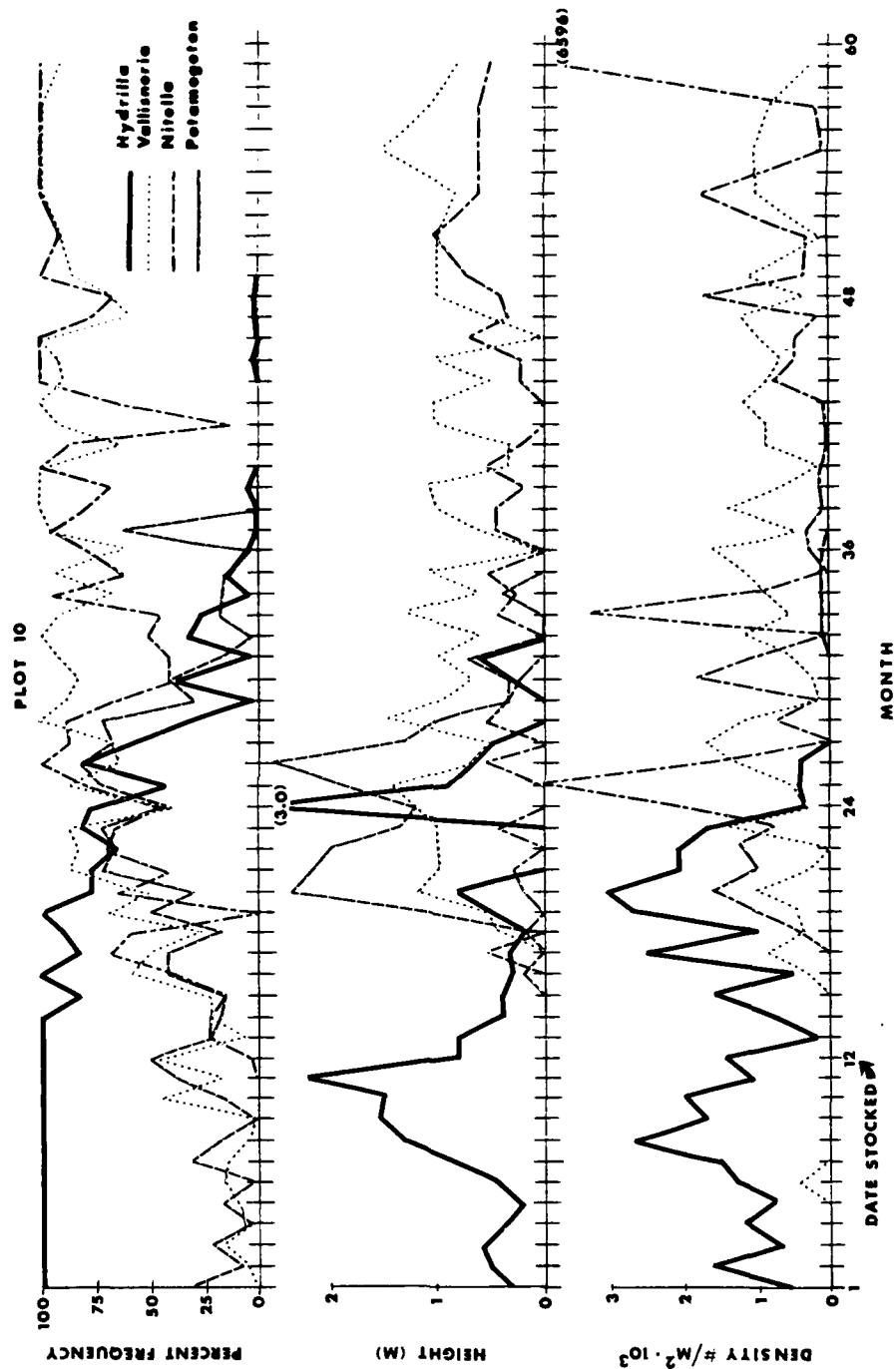


Figure 16. West Pool plot sample

entire baseline year. The other three major species were present but usually in trace amounts. *Hydrilla* was removed from the plot by the end of PS2 allowing *Nitella*, *Potamogeton*, and *Vallisneria* to increase. Midway through PS2, *Nitella* and *Potamogeton*, two preferred species, began to decline and *Vallisneria* became the dominant plant during PS3. A rapid increase in *Nitella* density during PS4 began to force out the *Vallisneria*, and *Nitella* was the dominant plant at the end of the study.

## CONCLUSIONS

The following conclusions can be drawn:

- a. White amur can effectively control preferred species of vegetation. The order of preference for the major species in Lake Conway was *Hydrilla*, *Potamogeton*, *Nitella*, and *Vallisneria*.
- b. White amur should be used only if eradication of preferred vegetation is desirable or tolerable. There is no control over areas in which white amur will feed after they are placed into the system. If there is desirable vegetation in the system that is also preferred by the white amur, for example *Nitella* in Lake Conway, it will eventually fall under the same feeding pressure as the nondesirable target species.
- c. White amur should not be used to control nonpreferred species of vegetation when desirable preferred vegetation is present. The preferred species will disappear first, leaving open areas for the nonpreferred target species to colonize, possibly resulting in a greater problem than originally encountered.
- d. If eradication is desired, white amur should be stocked in concentrations large enough to achieve eradication within 2 years. Osborne\* reports that white amur over 14.1 kg eat only enough vegetation to maintain body weights. The Lake Conway amur grew from an average of 0.45 kg at the stocking date to 11.36 kg after 3 years in the lake. Despite the natural drawdown during PS4, total vegetation and the preferred species *Nitella* began to increase in frequency and standing crop.
- e. White amur should be stocked in early spring, after the winter vegetation die-off, or after a chemical treatment, while standing crops are at a minimum. The amur can immediately begin to reduce vegetation from the base amounts present in the system. If stocked during the peak growing season, white amur may at best be able to control the new vegetation growth. If stocked at the end of the growing season, the amur may remain small throughout the winter and be more available as prey to carnivorous fish. Osborne\*\* recommends a stocking rate of twenty 0.50-kg fish per metric ton of *Hydrilla* to achieve eradication in 1 year.
- f. Additional white amur should be stocked within 3 to 4 years if eradication is not achieved. White amur grown in a climate similar to central Florida will be in the 11- to 14-kg range and will have decreased their consumption rate and lost their ability to control heavy growths of vegetation.

\* Osborne, J. A., and Sassic, N. E. 1981. "The Size of Grass Carp as a Factor in the Control of *Hydrilla*," *Aquatic Botany*, Vol 11, pp 129-136.

\*\* Personal Communication, John Osborne, unpublished data.

# LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

## Fish, Waterfowl, and Mammals

by  
Scott Hardin\*

The Florida Game and Fresh Water Fish Commission has investigated the effects of white amur (*Ctenopharyngodon idella*) introduction on fish, waterfowl and wading birds, and aquatic mammals of Lake Conway. This report details some of the major findings of the study.

### DESCRIPTION OF THE STUDY AREA

Lake Conway is a 747-hectare (1820-acre) lake located in central Florida in south Orange County. The average altitude is 25.7 m mean sea level (msl), average air temperature is 22° C, and average annual rainfall is 130 cm. There is one inflow stream, and one outflow stream that drains into the Kissimmee Valley Chain of Lakes.

The principal submergent vegetation consists of nitella (*Nitella furcata*) and eelgrass (*Vallisneria americana*). Initially, Illinois pondweed (*Potamogeton illinoensis*) and hydrilla (*Hydrilla verticillata*) were abundant but declined in poststocking years II and III (1978-79 and 1979-80), until the final year of the study when a resurgence was observed, particularly for the former species. Emergent vegetation is lacking in much of the lake due to removal by home owners and falling water levels which exposed littoral areas. Only a few natural areas remain with stands of cattail (*Typha latifolia*), pickerelweed (*Pontederia cordata*), umbrella grass (*Fuirena scirpoides*), and maidencane (*Panicum hemitomom*). The substrate is primarily sand with some areas of organic muck.

Lake Conway is a relatively deep lake for central Florida, with a maximum depth of 10 m in Middle Pool and depths up to 7 m in each of the remaining pools. Six percent of the lake is less than 1 m deep and only fifteen percent is less than 2 m (Nall and Schardt 1978).

### METHODS AND MATERIALS

#### Fish

Three basic habitats occur in Lake Conway: shallow littoral (less than 2 m), deeper littoral, and limnetic or open water. Wegener rings (Wegener, Holcomb, and Williams 1973) were employed to quantitatively sample shallow water littoral fish

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\* Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

populations. Nocturnal electrofishing was used to sample deeper littoral fishes with stations in both vegetated and nonvegetated areas to determine differences between these categories. Gill nets were used to characterize relative abundance and species composition of open-water fish populations.

Block nets were set in the spring and fall to determine total fish standing crop, relative abundance of sport and forage fishes, reproductive success of major sport species, and total species composition. A roving creel survey was conducted throughout the study to monitor the sport-fishery (Pfeiffer 1967). Stomach contents of white amur were identified and quantified.

### **Waterfowl and wading birds**

Periodic surveys of all waterfowl and wading birds were made by touring the lake and recording the numbers of all species sighted. An airboat was used to flush birds from cattails and other vegetative cover. During winter, specimens of American coot (*Fulica americana*) and ring-necked duck (*Aythya collaris*), the principal migratory species, were taken by shotgun for food habit analysis.

### **Aquatic mammals**

Systematic trapping was conducted quarterly at four sites to determine trends in aquatic mammal abundance. Tomahawk, double-door, treadle-operated traps were set to capture larger mammals — raccoon (*Procyon lotor*) and opossum (*Didelphis marsupialis*); Sherman traps were used to sample small animals such as hispid cotton rats (*Sigmodon hispidus*) and rice rats (*Oryzomys palustris*); and a special trap was used to capture Florida water rats (*Neofiber alleni*). Counts of Florida water rat nests were made at four sites quarterly.

## **RESULTS AND DISCUSSION**

### **Fish**

Lake Conway has topographical features that affect its fish population structure. In the absence of extensive shallow areas with emergent vegetation that harbors dense fish and invertebrate organism populations, fish in Lake Conway utilize deeper littoral habitat with abundant submersed vegetation.

Wegener ring samples indicate a depauperate shallow water fish fauna compared to nearby lakes with greater littoral vegetation (Wegener and Williams 1976; Holcomb et al. 1977; Johnson et al. 1978; Williams et al. 1980). Wegener ring yields were larger in the baseline year, declined when low water levels eliminated much desirable littoral habitat, and increased with increasing water level in the final study year (Table 1). Electrofishing results demonstrated the importance of vegetation to fish populations (Figure 1). While samples from nonvegetated beach areas almost always yielded more fish per sample, these were small individuals, primarily brook silverside (*Labidesthes sicculus*), along with coastal shiner (*Notropis petersoni*), small bluegill (*Lepomis macrochirus*), and small redear (*L. microlophus*). Weight per sample from vegetated areas was greater than that from

**Table 1**  
**Number and Weight of Fish per Sample in Wegener Rings,**  
**Lake Conway, Florida, 1976-1980**

Fish	1976-77		1977-78		1978-79		1979-80	
	No.	Wt., g	No.	Wt., g	No.	Wt., g	No.	Wt., g
Black crappie	-	-	-	-	0.0	0.00	-	-
Bluefin killifish	7.4	5.32	4.2	1.16	1.0	0.31	8.2	2.38
Bluegill	0.5	9.49	0.6	1.22	0.3	1.49	2.3	12.37
Bluespotted sunfish	0.4	0.58	0.3	0.27	0.2	0.20	1.1	0.60
Brook silverside	-	-	0.0	0.03	-	-	-	-
Brown bullhead	-	-	0.0	0.01	-	-	-	-
Chain pickerel	0.0	0.01	0.0	0.77	0.0	0.34	-	-
Coastal shiner	2.0	1.87	0.3	0.24	0.9	0.18	11.9	3.87
Dollar sunfish	0.0	0.03	0.2	0.29	-	-	2.7	3.10
Flagfish	0.1	0.11	0.0	0.01	0.1	0.03	-	-
Florida gar	0.0	0.03	-	-	-	-	-	-
Golden shiner	-	-	0.0	0.04	-	-	-	-
Golden topminnow	0.4	1.79	0.3	0.37	0.4	0.49	0.7	1.03
Lake chubsucker	-	-	-	-	-	-	0.0	0.28
Largemouth bass	0.3	2.99	0.1	0.76	0.1	0.12	0.5	0.43
Least killifish	0.2	0.16	0.5	0.20	0.2	0.03	0.4	0.05
Mosquitofish	11.9	12.25	10.4	3.14	7.8	2.49	13.3	4.25
Redear sunfish	0.2	2.27	0.1	0.50	0.0	0.24	0.4	1.95
Sailfin molly	-	-	0.1	0.11	0.1	0.09	-	-
Seminole killifish	2.2	8.34	2.5	5.84	1.7	3.97	3.2	9.48
Spotted sunfish	-	-	0.0	0.32	-	-	-	-
Swamp darter	1.5	3.66	0.8	0.47	0.3	0.17	2.3	1.17
Warmouth	0.2	1.36	0.1	1.48	0.1	0.71	0.6	0.78
Yellow bullhead	-	-	0.0	0.01	-	-	-	-
Total	27.3	50.26	20.5	17.24	13.2	10.86	47.6	41.74

beach sites except for the final sample. Shannon-Weaver diversity index values (Pielou 1966) for vegetated areas were larger, indicating a more equitable distribution of numbers among species. The vegetation on sample sites was almost exclusively emergent and was not reduced during the study.

Gill net samples indicated an abundant limnetic population of largemouth bass (*Micropterus salmoides*), Florida gar (*Lepisosteus platyrhincus*), and gizzard shad (*Dorosoma cepedianum*) (Table 2). Bass were often captured in schools which were abundant in the first two years of the study. Anglers were observed pursuing these schools of fish which apparently were feeding on brook silversides. The utilization of open water by largemouth bass, a species normally considered to frequent littoral areas, may be due to the paucity of shallow littoral habitat, the concentration of limnetic forage by extensive deeper littoral plant communities, and the difficulty of foraging among dense underwater vegetation with little "edge effect." Schools of bass were rare in the final 2 years; this may have resulted from the reducing of vegetation which rendered forage species in deeper littoral areas vulnerable to predation. Nonetheless, bass were abundant in gill net samples throughout the study. Increased sample intervals in 1978-79 and 1979-80 may have resulted in reduced yields per net day in this period.

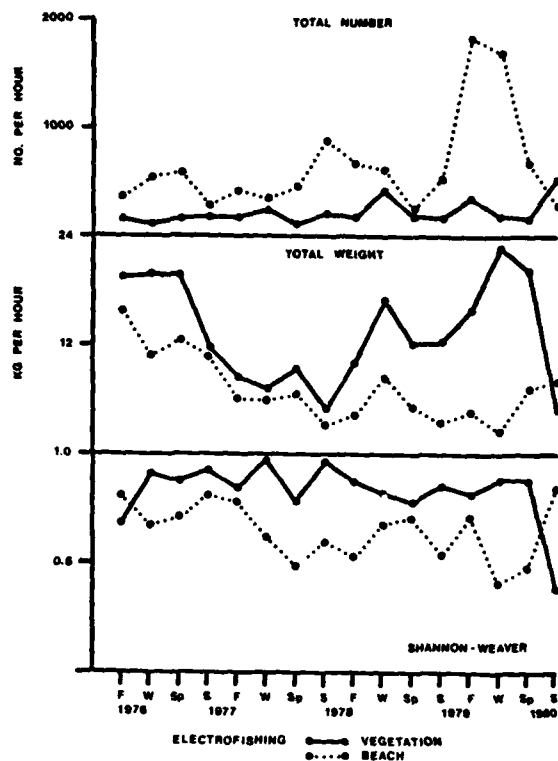


Figure 1. Average total number and total weight (kilograms) per hour and Shannon-Weaver diversity index values for electrofishing vegetated and nonvegetated beach sites, Lake Conway, Florida, 1976-80

Table 2  
Average Number and Weight of Fish per Net Day in Gill Net Samples,  
Lake Conway, 1976-1980

Fish	1976-77		1977-78		1978-79		1979-80	
	No.	Wt., kg	No.	Wt., kg	No.	Wt., kg	No.	Wt., kg
Florida gar	7.5	6.5	6.6	4.9	2.5	2.4	1.2	1.6
Gizzard shad	7.6	4.5	4.9	2.8	3.6	1.8	1.6	1.1
Chain pickerel	1.8	1.1	1.4	0.9	0.4	0.3	0.6	0.4
White amur	-	-	<0.1	0.1	0.1	0.5	-	-
Golden shiner	1.1	0.3	0.7	0.3	0.4	0.1	0.2	<0.1
Lake chubsucker	0.4	0.2	0.8	0.4	0.6	0.4	0.6	0.4
Yellow bullhead	0.4	0.1	0.5	0.3	0.5	0.3	0.6	0.4
Brown bullhead	0.2	0.1	0.2	0.1	<0.1	<0.1	0.2	0.1
Warmouth	0.1	<0.1	0.3	0.1	-	-	<0.1	<0.1
Bluegill	0.1	0.1	0.7	0.1	0.2	0.1	0.2	<0.1
Redear sunfish	0.2	<0.1	0.4	0.1	0.2	0.2	0.1	<0.1
Largemouth bass	7.4	3.8	8.7	4.2	6.6	3.7	4.3	3.5
Black crappie	3.9	0.9	1.8	0.5	1.0	0.2	0.6	0.1
Bowfin	-	-	-	-	-	-	<0.1	<0.1

Blocknets indicated the density of fish populations in deeper littoral habitats (Table 3). Set in areas with abundant submersed vegetation, these samples produced over 40,000 fish per hectare in the first two study years. Large numbers of bluespotted sunfish (*Enneacanthus gloriosus*), a small centrarchid which carries out its life cycle among underwater plants, was the most numerous species, but large numbers of juvenile largemouth bass, bluegill, and redear sunfish were captured also.

Blocknet samples revealed the effects of the reduction of vegetation in poststocking years II and III. Beginning in fall 1978, total numbers declined, reaching a minimum 1 year later (Figure 2). Thereafter, numbers never did approach original densities. The decline was due primarily to a loss of bluespotted sunfish resulting from a reduction in habitat (Figure 2). Unfortunately, ecological relationships involving bluespotted sunfish are poorly understood, and the consequence of their decrease on benthic invertebrates and predatory fish is

Table 3  
Number and Weight of Fish per Hectare from Blocknet Samples,  
Lake Conway, Florida, 1976-1981

Fish	1976-77		1977-78		1978-79		1979-80		1980-81	
	No.	Wt., kg	No.	Wt., kg	No.	Wt., kg	No.	Wt., kg	No.	Wt., kg
<b>Fall:</b>										
Black crappie	40	0.76	21	0.27	127	1.94	6	0.26	10	1.85
Bluefin killifish	235	0.08	516	0.23	718	0.33	22	0.01	10	<0.01
Bluegill	1,719	18.67	1,442	19.35	6,196	27.76	1,502	34.45	497	15.12
Bluespotted sunfish	17,276	9.68	12,786	12.91	21,225	17.26	487	0.23	850	0.28
Brook silverside	-	-	-	-	-	-	4	<0.01	2	<0.01
Brown bullhead	-	-	-	-	-	-	5	0.18	1	0.01
Chain pickerel	34	8.46	40	4.71	50	10.38	24	6.74	8	3.02
Coastal shiner	28	0.01	-	-	9	0.01	12	0.01	2	<0.01
Dollar sunfish	89	0.13	280	0.33	366	0.89	15	0.05	9	0.02
Flagfish	8	0.01	-	-	-	-	-	-	-	-
Gizzard shad	-	-	-	-	-	-	1	0.46	-	-
Golden shiner	8	0.50	83	2.26	55	1.85	179	17.47	10	0.64
White amur	-	-	-	-	2	13.07	5	30.50	2	15.11
Lake chub	2	1.13	2	0.08	2	1.48	10	5.10	1	0.77
Largemouth bass	496	31.57	472	23.70	416	31.48	201	33.79	237	13.49
Redear sunfish	1,078	23.60	1,126	13.42	4,299	22.62	279	10.72	396	25.36
Seminole killifish	228	1.02	256	1.00	104	0.42	16	0.07	112	0.59
Spotted sunfish	-	-	-	-	3	0.01	-	-	741	0.25
Swamp darter	53	0.01	25	0.02	63	0.06	4	<0.01	2	<0.01
Tadpole madtom	4	0.01	2	<0.01	-	-	13	0.01	2	<0.01
Threadfin shad	317	1.78	2,629	19.03	7	0.03	1	<0.01	5	0.02
Warmouth	548	2.33	343	2.46	669	3.62	15	0.22	30	0.59
Yellow bullhead	2	0.05	1	0.01	-	-	-	-	-	-
<b>Total</b>	<b>22,165</b>	<b>99.80</b>	<b>20,024</b>	<b>99.79</b>	<b>34,311</b>	<b>133.21</b>	<b>2,801</b>	<b>140.30</b>	<b>2,927</b>	<b>77.17</b>

(Continued)

Table 3 (Concluded)

Fish	1976-77		1977-78		1978-79		1979-80		1980-81	
	No.	Wt., kg	No.	Wt., kg	No.	Wt., kg	No.	Wt., kg	No.	Wt., kg
<b>Spring:</b>										
Black crappie	26	0.22	2,148	0.48	12	0.43	9	1.95	23	0.01
Bluefin killifish	318	0.15	3,426	1.91	393	0.15	107	0.21	215	0.11
Bluegill	1,540	15.00	2,633	17.36	944	14.87	1,294	32.37	923	18.78
Bluespotted sunfish	47,540	26.62	37,480	19.96	2,613	1.93	561	0.48	1,025	0.83
Bowfin	-	-	-	-	-	-	1	2.96	-	-
Brook silverside	-	-	-	-	8	0.02	1,075	0.49	28	0.03
Brown bullhead	-	-	-	-	6	0.73	5	2.68	-	-
Chain pickerel	251	8.76	133	12.46	62	11.71	60	10.34	101	4.21
Coastal shiner	1	<0.01	575	0.40	1	0.01	1	0.01	15	0.01
Dollar sunfish	256	0.50	386	1.15	213	0.47	487	0.78	104	0.25
Florida gar	1	0.32	-	-	-	-	2	2.31	-	-
Gizzard shad	4	2.13	-	-	2	1.03	2	1.59	-	-
Golden shiner	5	0.39	220	2.28	90	4.14	29	2.31	3	0.15
White amur	-	-	-	-	1	5.63	1	5.43	3	38.02
Lake chubsucker	-	-	-	-	1	0.52	3	2.47	-	-
Largemouth bass	7,436	17.66	4,257	23.34	393	22.32	1,074	41.87	554	16.14
Redear sunfish	1,526	12.91	1,456	25.93	544	11.62	545	14.56	564	19.43
Seminole killifish	8	0.04	189	0.80	6	0.04	30	0.12	39	0.27
Spotted sunfish	-	-	-	-	-	-	3	0.01	-	-
Swamp darter	8	<0.01	1	<0.01	2	<0.01	-	-	1	<0.01
Tadpole madtom	-	-	-	-	-	-	3	0.01	4	0.01
Threadfin shad	91	0.42	22	0.20	82	0.34	895	8.95	-	-
Warmouth	476	3.23	1,369	9.15	588	3.33	75	1.26	56	1.03
Yellow bullhead	1	0.01	92	0.48	2	0.01	-	-	1	0.09
Total	59,488	88.38	54,387	115.91	5,963	79.31	6,262	133.16	3,659	99.38

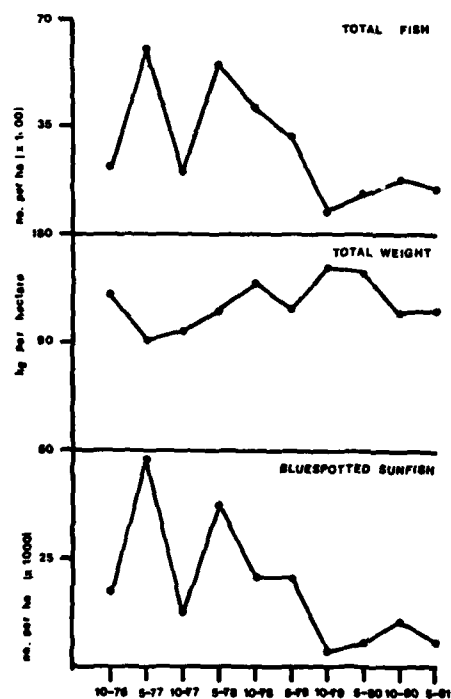
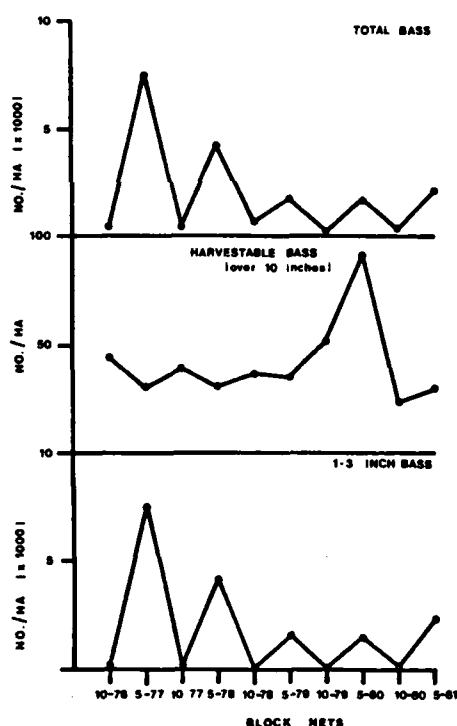


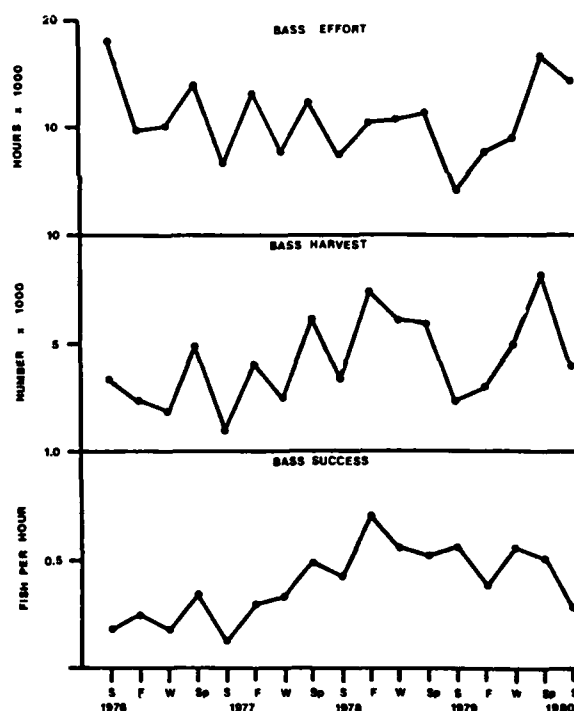
Figure 2. Average total number and total weight (kilograms) of fish per hectare and average number of bluespotted sunfish per hectare in block-net samples, Lake Conway, Florida, 1976-81

Total numbers of largemouth bass in blocknets declined during the study with the greatest reduction occurring for small fish (2.54 to 7.62 cm). However, numbers of harvestable bass increased slightly (Figure 3). The extremely large value in May 1980 resulted because the fixed sample site was located in the only submersed vegetation in the area. This value is not representative of the bass population, but does emphasize the importance of vegetation in the lake. In the final samples when vegetation cover was increasing, harvestable numbers declined and numbers of small fish increased. Had vegetation remained at minimum levels, recruitment of largemouth bass may have suffered with an attendant decline in the fishery.

Largemouth bass was the predominant sportfish in Lake Conway. Creel results indicated a seasonal fishery with the least effort expended during the summer (Figure 4). Extremely low water levels occurring in the winters of 1977-78 and 1978-79 and summer 1977 restricted pool-to-pool access and affected angler participation. Bass harvest was also seasonal and correlated with effort, but an



**Figure 3. Average total number of largemouth bass, number of harvestable bass, and number of 1- to 3-in. bass per hectare in blocknet samples, Lake Conway, Florida, 1976-81**



**Figure 4. Estimated angler effort (hours), harvest, and success (fish per hour) for largemouth bass in Lake Conway, Florida, 1976-81**

increase was observed during the study. Success (fish per hour) was greater in 1978 and 1979, the period of minimum plant abundance. Success values of up to 0.7 bass per hour represent excellent bass fishing compared to the national average of 0.2 (Guillory 1979). With the resurgence of vegetation near the conclusion of the study, success appeared to be declining, although a seasonal decrease would be expected at this time. Creel results corroborated blocknet samples, indicating sportfish were concentrated and more accessible to anglers.

Apparently, the reduction in vegetation in poststocking years II and III concentrated sportfish. The availability of a forage base previously concealed in underwater vegetation benefited sportfish: increased robustness was observed for bass greater than 300 mm total length during this period. However, production of juvenile sportfish and forage species suffered. A general worsening in condition of bass less than 300 mm and bluegill was noted, and abundance of bluespotted sunfish was adversely affected. Although beneficial effects were observed among harvestable sportfish, the lack of production of juveniles and an adequate forage base portends a future deterioration of the fishery. The minimum vegetation cover during the study is not felt to be sufficient to maintain the sport fishery at the levels observed. However, the increase in submersed plants in the final year may negate or mitigate the trends observed.

White amur initially consumed Illinois pondweed, nitella, and hydrilla (Figure 5). Hydrilla was eliminated from the lake and became unimportant as a food item, while nitella and Illinois pondweed continued to be consumed. Filamentous algae increased in percent occurrence and volume becoming the principal food item by 1979-80, reflecting decreased selectivity among older fish (Hickling 1967). The number of empty fish increased each year, and it appears that as white amur reach a certain age, consumption rate decreases. Growth of white amur was linear through the study but appeared to be leveling off in the final months. Not enough is known about mortality, consumption by older fish, and changes in food preference to accurately predict a stocking rate or vegetation response. Apparently, control in Lake Conway has been limited to a few years rather than several as was initially thought, a phenomenon observed by other authors (Colle et al. 1978; Osborne and Sassic 1979; Hardin and Atterson 1980). The pattern of total elimination of preferred plant species casts doubt on the ability of white amur alone to maintain desirable vegetation levels to support fisheries habitat. Furthermore, if loss of control was due to reduced consumption rather than mortality, then restocking may result in large standing crops of white amur that may impact native fish populations.

#### **Waterfowl and wading birds**

Total numbers of waterfowl and birds per survey declined through the study (Figure 6). Little change was noted in abundance of wading birds, and the decrease was due primarily to fewer American coots (Figure 7). Coot abundance is affected by weather, and reduced numbers in 1977-78 corresponds to a statewide trend. However, the continuing decline appears to be related to a loss of food items in the

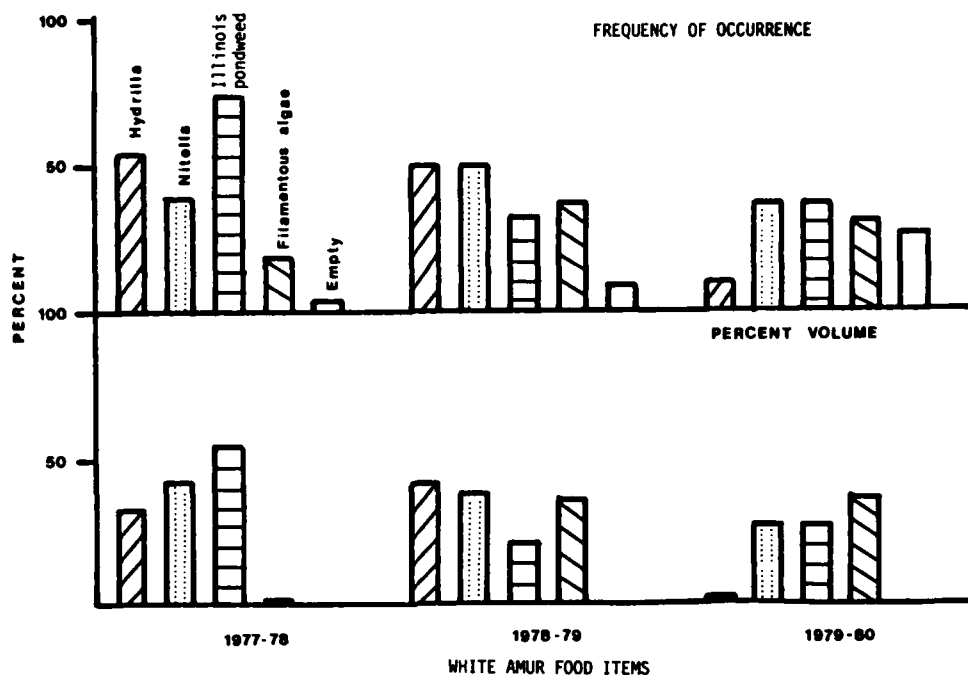


Figure 5. Frequency of occurrence and aggregate percent volume of food items of white amur, Lake Conway, Florida, 1977-80

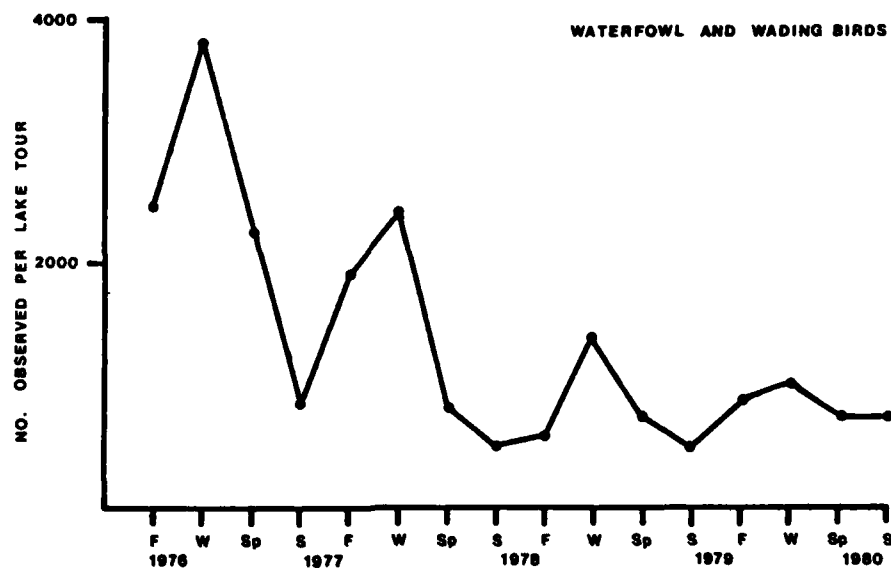


Figure 6. Total number of waterfowl and wading birds observed per lake tour, Lake Conway, Florida, 1978-80

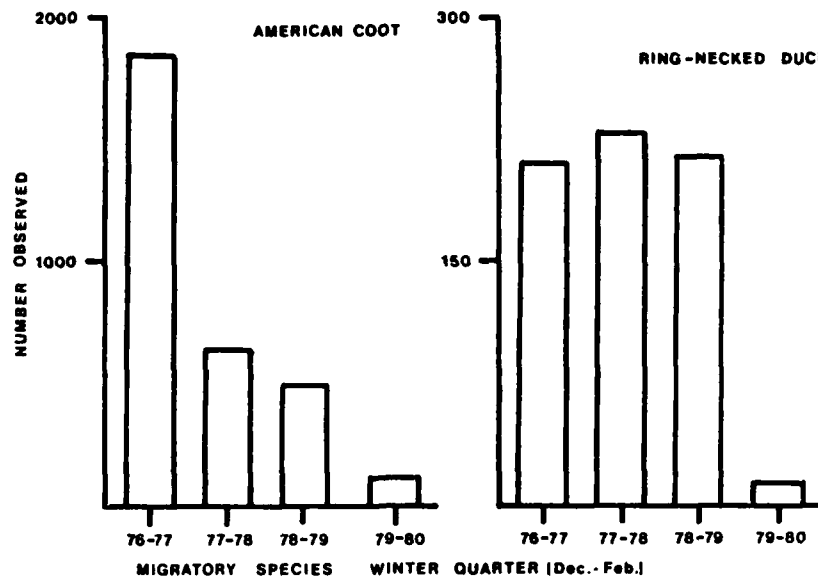


Figure 7. Number of American coots and ring-necked ducks observed per lake tour in winter (December-February), Lake Conway, Florida, 1976-80

form of aquatic plants. American coots sampled on Lake Conway had fed on hydrilla, Illinois pondweed, and nitella. The first two species were nearly eliminated, and nitella occurred below 2 m depth. Coots prefer surface feeding and may have sought other water bodies with more abundant shallow vegetation. Ring-necked ducks were less abundant than coots and their numbers remained stable until the winter of 1979-80, when a drastic decline occurred. This species consumed nitella oogonia and both seeds and vegetative portions of Illinois pondweed. Although only one survey was conducted the winter of 1981, casual observation indicated fewer birds present, and the decline is attributed partially to a loss of food items. Because of the similarity between their diets, white amur should not be stocked where waterfowl are an important resource.

#### Aquatic mammals

Aquatic mammals were mostly shoreline inhabitants and were affected primarily by clearing activities associated with home building. Two sites were completely destroyed and a third was altered. Most mammals captured were not dependent on aquatic vegetation and are unlikely to be affected by the white amur.

The Florida water rat, a species of special concern, inhabited littoral vegetation, building nests in pickerelweed, maidencane, and waterhyacinth (*Eichhornia crassipes*). By the end of the study, almost all nests had been destroyed by beach clearing or falling water levels. No animals were captured the final year, but several burrows were observed, indicating an adaptability to low water (Birkenholz 1963; Tilmant 1975). Because emergent vegetation was not consumed, water rat populations were not affected by white amur stocking. However, with older white amur and a lack of submersed plants, the potential for impact on water rat habitat exists.

## REFERENCES

- Birkenholz, D. E. 1963. "A Study of the Life History and Ecology of the Round-Tailed Muskrat (*Neofiber alleni* true) in North-Central Florida," *Ecological Monographs*, Vol 33, pp 107-213.
- Colle, D. E., et al. 1978. "Utilization of Selective Removal of Grass Carp (*Ctenopharyngodon idella*) from an Eighty Hectare Florida Lake to Obtain a Population Estimate," *Transactions of the American Fisheries Society*, Vol 107, No. 5, pp 724-729.
- Guillory, V. 1979. Large-Scale Operations Management Test of Use of the White Amur for Control of Problem Aquatic Plants; Report 1, Baseline Studies; Vol II: The Fish, Mammals, and Waterfowl of Lake Conway, Florida," Technical Report A-78-2, prepared for U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Hardin, S., and Atterson, J. 1980. "Ecological Effects of Grass Carp Introduction in Lake Wales, Florida," Florida Game and Fresh Water Fish Commission, Mimeo Report, Tallahassee, Fla.
- Hickling, C. F. 1967. "On the Biology of the Herbivorous Fish, the White Amur or Grass Carp, *Ctenopharyngodon idella*, Val.," *Proc. R. Soc. Edinburgh Sect. B*, Vol 70, No. 1, pp 62-81.
- Holcomb, D., et al. 1977. "Upper Oklawaha Basin Fisheries Investigations Project," Annual Progress Report, D-J Project, F-30, Florida Game and Fresh Water Fish Commission, Mimeo Report.
- Johnson, W. E., et al. 1978. "Oklawaha Basin Fisheries Investigations, Study III: Lake Carlton Rehabilitation Evaluation," Annual Progress Report, D-J Project F-30-5, Florida Game and Fresh Water Fish Commission, Tallahassee, Fla.
- Nall, L. E., and Schardt, J.D. 1978. "Large-Scale Operations Management Test of Use of the White Amur for Control of Problem Aquatic Plants; Report 1, Baseline Studies; Vol I: The Aquatic Macrophytes of Lake Conway, Florida," Technical Report A-78-2, prepared for U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Osborne, J. A., and Sassic, N. M. 1979. "Biological Control of *Hydrilla verticillata* Royle with Grass Carp (*Ctenopharyngodon idella* Val.)," *Journal of Aquatic Plant Management*, Vol 17, pp 45-48.
- Pfeiffer, P. 1967. "The Results of a Non-Uniform Probability Creel Survey on a Small State-Owned Lake," *Proceedings of the Southeastern Association Game and Fish Commission*, Vol 20, pp 409-412.
- Pielou, E. 1966. "Shannon's Formula as a Measure of Specific Diversity: Its Use and Misuse," *American Naturalist*, Vol 100, pp 403-465.
- Tilmant, J. T. 1975. *Habitat Utilization of Round-Tailed Muskrats (Neofiber alleni) in Everglades National Park*, M. S. Thesis, Humboldt State University, Humboldt, Calif.
- Wegener, W., Holcomb, D., and Williams, V. 1973. "Sampling Shallow Water Fish Populations Using the Wegener Ring," *Proceedings of the Southeastern Association Game and Fish Commission*, Vol 27, pp 663-664.

Wegener, W., and Williams, V. 1976. "Water Level Munipulation Project," Annual Progress Report, D-J Project F-29-5, Florida Game and Fresh Water Fish Commission, Mimeo Report.

Williams, V. P., et al. 1980. "Water Level Manipulation Project, Study V: Lake Kissimmee Monitoring," Annual Progress Report, D-J Project F-29-9, Florida Game and Fresh Water Fish Commission, Tallahassee, Fla.

# LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

## The Herpetofauna

by  
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Roy W. McDiarmid\*\*

As part of the Corps' Large-Scale Operations Management Test (LSOMT), the University of South Florida has been investigating since June 1977 the possible effects of the white amur (*Ctenopharyngodon idella*) on the native amphibians and reptiles of Lake Conway. This report summarizes changes observed in the herpetofaunal populations on this lake system during the period October 1980 to September 1981. White amur were stocked in Lake Conway in September 1977.

Details of the herpetofaunal sampling program on Lake Conway are presented elsewhere,† and only a brief summary is given herein. During the first three study years, amphibians and reptiles were monitored primarily by bimonthly funnel trapping and bimonthly censusing (herp-patrol) of five permanent shoreline sites (Figure 1). All individuals captured on these sites were measured, weighed, permanently marked, and released at the capture point for long-term mark and recapture population studies. Destructive samples of selected species were taken monthly from distant areas of similar habitat on the lake system. During the fourth study year, identical procedures were used except that the sampling program was reduced to a quarterly schedule. Under this sampling scheme, each permanent shoreline site was funnel trapped and herp-patrolled on two consecutive days in January, April, July, and October 1981.

During the fourth study year, 1,287 individuals representing 7 species of amphibians and 12 species of reptiles were observed or captured on Lake Conway. This sample equals 9.96 percent of the total number of individuals (12,927) and 70.37 percent of the total number of species (27) observed during the previous 3 years. One new species (*Chrysemys picta*) was added to the herpetofaunal list of Lake Conway during the fourth year (Table 1). A single individual of this introduced turtle species (probably a released pet) was collected in East Pool; the species is not believed to be established in Lake Conway.

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† Godley, J. S., McDiarmid, R. W., and Bancroft, G. T., 1981. "Large-Scale Operations Management Test of Use of the White Amur for Control of Problem Aquatic Plants; Report 1, Baseline Studies; Volume V: The Herpetofauna of Lake Conway, Florida," Technical Report A-78-2, prepared by University of South Florida, Tampa, Fla., for the U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

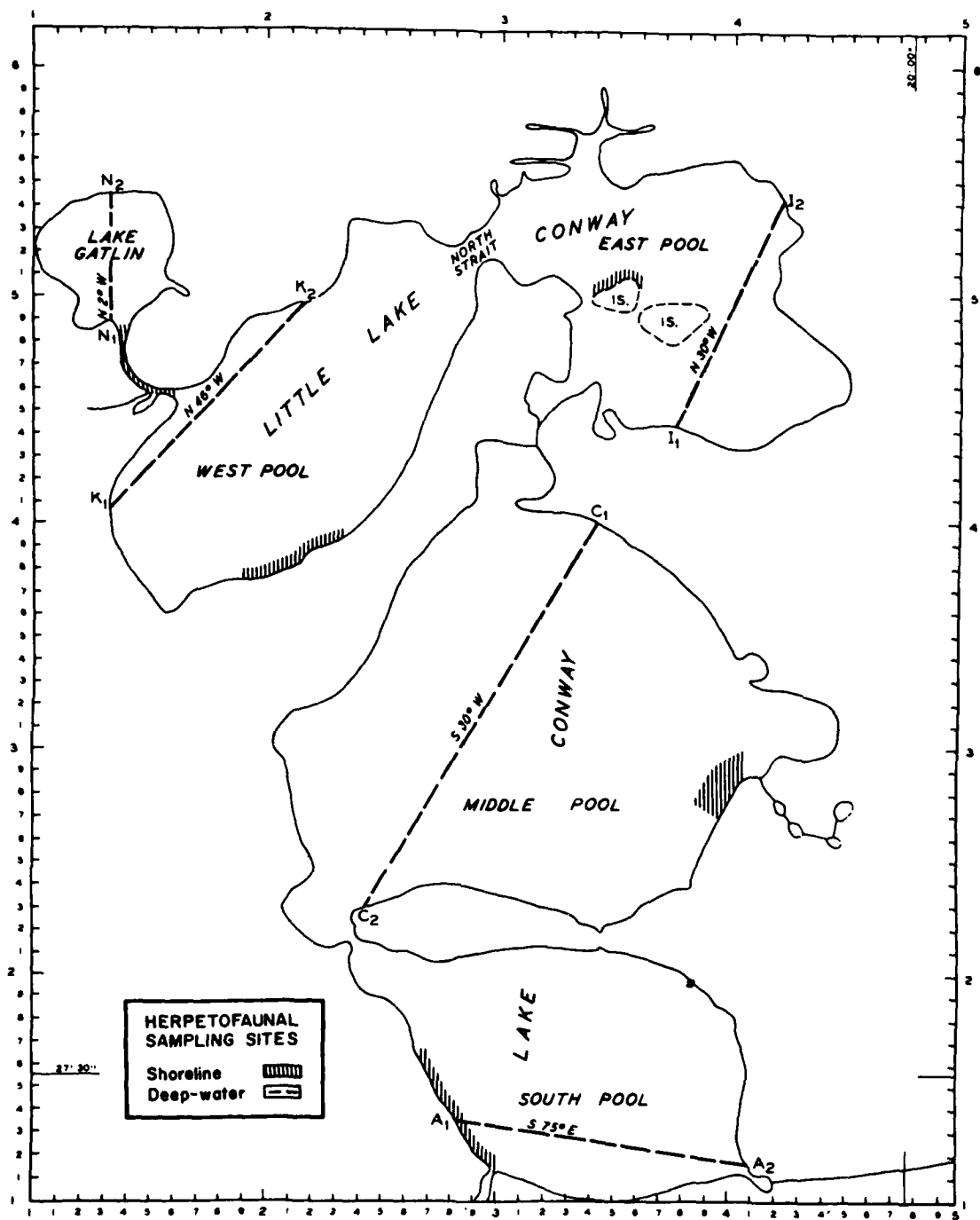


Figure 1. Permanent sampling sites for amphibians and reptiles on Lake Conway

Table 1  
Checklist of Amphibians and Reptiles Known from the Lake Conway System.

Scientific Name	Common Name	Scientific Name	Common Name
Amphibia		Testudinata	
Caudata		Chelydridae	
Sirenidae		<i>Chelydra serpentina</i>	Florida snapping turtle
<i>Pseudobranchius striatus</i>	Dwarf siren	Kinosternidae	
<i>Siren lacertina</i>	Greater siren	<i>Kinosternon baurii</i>	Striped mud turtle
Amphiumidae		<i>Kinosternon subrubrum</i>	Eastern mud turtle
<i>Amphiuma means</i>	Two-toed amphiuma	<i>Sternotherus odoratus</i>	Stinkpot
Plethodontidae		Emydidae	
<i>Eurycea quadridigitata</i>	Dwarf salamander	<i>Chrysemys picta</i> *	Painted turtle
Anura		<i>Pseudemys floridana</i>	Peninsular cooter
Bufonidae		<i>Pseudemys nelsoni</i>	Florida red-bellied turtle
<i>Bufo terrestris</i>	Southern toad	<i>Pseudemys scripta</i> *	Red-eared turtle
Microhylidae		<i>Deirochelys reticularia</i>	Chicken turtle
<i>Gastrophryne carolinensis</i>	Eastern narrow-mouthed toad	Trionychidae	
Ranidae		<i>Trionyx ferox</i>	Florida softshell
<i>Rana grylio</i>	Pig frog	Squamata	
<i>Rana utricularia</i>	Southern leopard frog	Colubridae	
Hylidae		<i>Coluber constrictor</i>	Black racer
<i>Acris gryllus</i>	Florida cricket frog	<i>Farancia abacura</i>	Mud snake
<i>Hyla cinerea</i>	Green treefrog	<i>Nerodia cyclopion</i>	Green water snake
<i>Hyla femoralis</i>	Pinewoods treefrog	<i>Nerodia fasciata</i>	Florida water snake
<i>Hyla squirella</i>	Squirrel treefrog	<i>Regina alleni</i>	Striped swamp snake
Reptilia		<i>Thamnophis sauritus</i>	Peninsula ribbon snake
Crocodylia		<i>Thamnophis sirtalis</i>	Eastern garter snake
Crocodylidae			
<i>Alligator mississippiensis</i>	American alligator		

\* Introduced species.

For each permanent shoreline site on Lake Conway, Figures 2-4 summarize quarterly changes in the relative abundance of herpetofaunal species as determined by the two major sampling methods: herp-patrol (mean number/hour) and funnel trapping (mean number/100 trap days). It should be noted that, prior to winter 1981, each data point represents the mean of six evenly spaced samples for each 3-month period whereas after this date each point represents the mean of only two samples for each season.

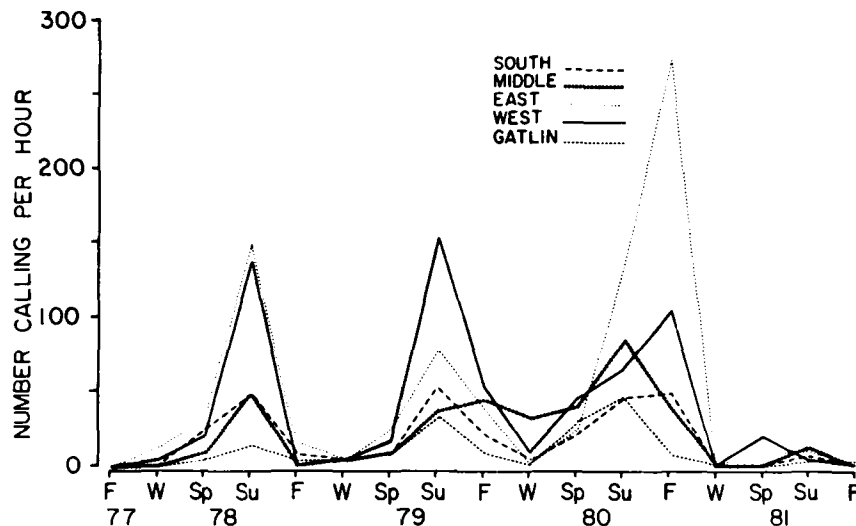


Figure 2. Relative density of male frogs heard calling on herp-patrols of the permanent shoreline sites on Lake Conway

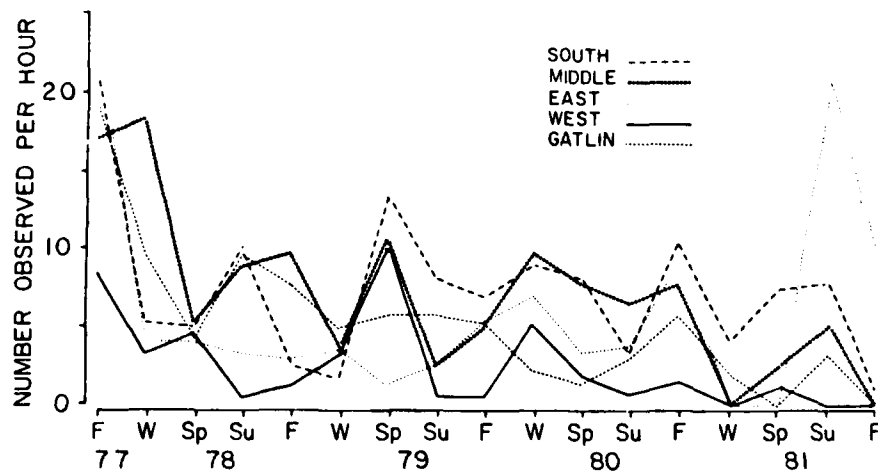


Figure 3. Relative density of salamanders and reptiles observed on herp-patrols of the permanent shoreline sites on Lake Conway

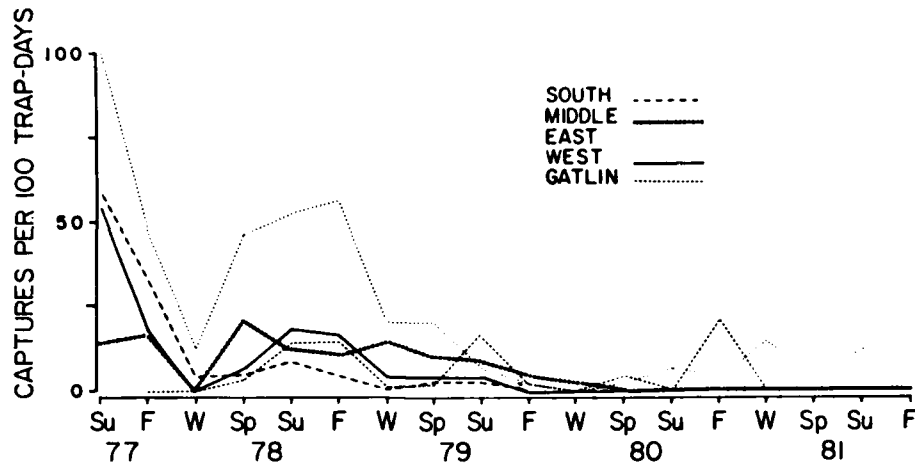


Figure 4. Relative density of amphibians and reptiles captured in funnel traps on the permanent sites on Lake Conway

The number of male frogs heard calling on herp-patrols showed the greatest change of any major group during the fourth study year (Figure 2). The summer peak in calling activity, particularly of *Hyla cinerea* and *Acris gryllus*, which characterized the previous 3 years, was not recorded in 1981. In addition, no individuals of one common species (*Bufo terrestris*) were heard calling during the quarterly samples. This probably represents decreased frog calling activity during the quarterly sampling periods rather than true reduction in frog populations on Lake Conway. Both summer and fall 1981 sampling trips were characterized by dry weather, which generally inhibits frogs from calling.

Figure 3 shows quarterly changes in the mean number of salamanders and reptiles observed per hour on the permanent sites during herp-patrols. This group, which includes 2 species of aquatic salamanders and 12 species of reptiles, exhibits less seasonality and greater variability than frogs. The general trend is a gradual decrease in the relative abundance of these species on the permanent sites. This trend continued during the fourth study year. Species that showed significant reductions on at least some permanent sites include *Kinosternon subrubrum*, *Nerodia cyclopion*, *Pseudemys floridana*, and *Sternotherus odoratus*. No species consistently increased in relative density on these sites.

The relative density of amphibians and reptiles captured in funnel traps on permanent shoreline sites decreased significantly after the second year and this trend continued for the remainder of the study (Figure 4). Significant reductions in the relative abundance of five common species (*Amphiuma means*, *Siren lacertina*, *Kinosternon subrubrum*, *Sternotherus odoratus*, and *Nerodia cyclopion*) were primarily responsible for this trend.

The above results indicate that significant density changes have occurred in a number of herpetofaunal species on Lake Conway. The causes of these density

fluctuations are numerous and complex, varying with both the species and the sampling site. The tabulation below summarizes density responses of herpetofaunal groups on Lake Conway and attempts to identify major causative agents. Although most reductions in amphibian and reptile populations on Lake Conway are correlated with decreases in aquatic plant biomass as the result of white amur feeding activity, these reductions are, unfortunately, confounded by other factors.

<u>Taxon</u>	<u>Density Response</u>	<u>Water-Level Fluctuations</u>	<u>Human Disturbance</u>	<u>Predation</u>	<u>White Amur</u>
Salamanders	I	X	X	X	
Frogs	II	X	X		
Turtles	I		X		X
Snakes	I		X	X	
Alligator	I		X		

Human disturbance, primarily through destruction of littoral zone habitats, has had a significant negative effect on all the herpetofaunal species of Lake Conway. Reduced water levels during the final year of the study decreased the available littoral zone habitat, especially for frogs and salamanders. Decreased capture success of aquatic salamanders and snakes in funnel traps correlated with habitat destruction in South and Middle Pools and Gatlin Canal, and otter predation on trapped animals in East and West Pools.

Although declines in aquatic turtle populations on Lake Conway are also to some extent confounded by the above factors, chelonians show the clearest density response to vegetation removal by white amur. Of all major herpetofaunal groups, turtles probably are the most dependent on aquatic macrophyte productivity, and most susceptible to its removal. Two common herbivorous species (*Pseudemys floridana* and *P. nelsoni*) are direct competitors with amur for aquatic plants and another (*Sternotherus odoratus*) feeds primarily on snails which depend on macrophytes as a substratum. Although the responses of these turtle species in particular have been pronounced, the low stocking rate of amur on Lake Conway and the continued presence of macrophytes has ameliorated the effects of the fish on these turtles.

# **LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA**

## **Procedure for Radiotagging White Amur and Results of Radiotelemetry Tracking of White Amur in Lake Conway**

by  
Jeffrey D. Schardt,\* Gregory P. Jubinsky,\* and Larry E. Nall\*

### **INTRODUCTION**

To determine the correlation between vegetation declines and the presence of white amur, a study was initiated to determine the feasibility of using radiotelemetry techniques in Lake Conway. The study reviewed various types of equipment and concluded that a fish tracking study should be included in the Lake Conway project.

A greater understanding of white amur behavior was needed in the following areas: (1) movement, if any, during feeding, (2) relationships between water temperature and feeding activity, (3) food preference, (4) habitat preference, (5) diurnal activity patterns, (6) depth preference, (7) interchange among pools, (8) behavior variability among individuals, and (9) gregariness. Feeding activity was assumed by correlating fish presence and vegetation for extended periods. *Analysis of stomach contents* would have been necessary to confirm actual feeding and species consumed.

Background information and preliminary results were presented in November 1979 (Nall and Schardt 1980). This report updates radiotag implantation techniques and performance and summarizes the results of 26 months of white amur radiotelemetry results in Lake Conway.

### **METHODS AND MATERIALS**

The radiotag implantation procedure described in the following paragraphs is the culmination of tests performed to select the highest possible survival rate using the least expensive methods.

Fish used for radiotag implantation were obtained from other lakes and ponds using electroshocking or rotenone removal techniques (Colle et al. 1978). Only female fish of weights approximating those in Lake Conway were tagged. A temporary holding facility constructed of 1200-l cattle troughs with a lake water flow-through system was used to retain fish (maximum of four fish per tank) prior

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to surgery. Fish were observed for 1 day to allow recovery from capture and transportation.

Surgery was performed on a V-shaped trough that held the fish ventral side upward with the gills submersed in an 80-l aquarium. A 4-ppm quinaldine solution was used to anesthetize the fish in one of the holding tanks. Anesthetization was achieved when the fish could no longer maintain equilibrium, usually from 25 to 35 min. Five millilitres of 2 percent xylocaine was injected around the incision site 5 min before operating. The local anesthetic allowed the use of only a 4-ppm quinaldine solution in the surgical tank rather than the 15-ppm solution previously required. Recovery time was reduced to less than 5 min after returning the fish to fresh water.

Water was poured over the exposed portion of the fish during surgery to prevent drying. Three rows of scales were pulled from the incision site using hemostats. A 5-to 7-cm incision was cut vertically just anterior to the pelvic fin girdle and stopped 2 to 3 cm from the midventral line. This incision site was chosen because the radiotag and viscera might have placed a strain on sutures in a longitudinal midventral incision, causing it to reopen (Crumpton et al. 1978). This hypothesis was tested and proven correct. Radiotags were placed in the abdominal cavity and positioned at the lowest point. All instruments and tags were soaked in alcohol before use to provide some measure of sterility. Fish were confirmed to be female during surgery by the presence of eggs.

Closure was initially accomplished using 000 Type C chromic gut suture material. Four to six stitches were made through the body wall using a 6D half circle cutting suture needle. Five to seven shallower stitches were made through the epidermis and muscles using a smaller 8D half circle cutting needle, which ensured a tight closure. Individual rather than continuous sutures were used to prevent unravelling and reopening of the incision. Of the first 20 radiotags, 5 were rejected within 2 months after release, probably caused in part by the suture material dissolving before the incision sufficiently healed. In December 1979, six of nine tagged fish were closed with chromic gut and three with 000 Type B black braided silk. Thirty days later, those closed with silk had nearly healed while only three chromic gut sutures held. Two of the remaining fish died from the open wounds, the third was resutured with silk and released. All subsequent closures were made with braided silk.

After closure, 10 ml of injectable terramycin solution (50 mg/ml) oxytetracycline hydrochloride) was administered intramuscularly on either side of the dorsal fin. This was a dosage of approximately 55 mg oxytetracycline per kilogram of body weight. A maximum of 0.5 ml was administered in each injection site to avoid loss of the excess antibiotic when the needle was withdrawn. Intraperitoneal injections and antibiotic ointment applied directly to the incision were considered but rejected because of a suggestion that this might dissolve the suture material. Suggestions were also made that intramuscular injections of terramycin might cause lesions to form around the injection area. Thirty-three fish were observed

after receiving intramuscular injections and, although some swelling was evident for 2 to 3 days afterwards, no lesions formed.

The amur were initially held in the holding tanks for 1 day after surgery. Releasing the fish so soon after surgery may have contributed to the low survival rate (75 percent). Besides stress from capture, transporting, and tagging, warm water temperatures and unrestricted movement could have prevented proper healing of the incision (Smith and Bell 1967). The final 27 tagged fish were captured in cool weather and kept cool with ice during transportation. After implantation, they were held in 25-m<sup>2</sup> chain link structures built in the lake. The cages were lined with a 0.5-in. mesh, smooth, plastic screen to prevent injury while allowing water to circulate in the pen. A layer of waterhyacinths was placed in the cage to provide cover and discourage the fish from jumping. *Nitella* and *Potamogeton* were supplied for food during the observation period.

## RESULTS AND DISCUSSION

### Radio equipment

Radiotags used in the project were purchased from the AVM Instrument Company and the Wildlife Materials Company. The AVM tags, rated for a 58-month life, performed poorly as only 4 of 28 remained functioning after 29 months of use (Table 1). Housing design rather than electronic breakdown may have caused the problem. Upon recovery of two tags from dead fish, small cracks were noted in the epoxy covering the bases of the loop antennae. A quick movement by a fish could snap the epoxy covering the antenna wire and allow water to enter the electronic components.

The 25 tags from the Wildlife Materials Company were prepared with the antenna loop strengthened and completely covered with epoxy. Only two tag failures were recorded between January and October 1981 (Table 2). Signal reception was two to three times greater than with the AVM radiotags and could be received as far away as 1000 m if the transmitter depth was less than 3 m.

Table 1  
AVM Radiotag Performance Characteristics

<i>Fish No.</i>	<i>Pool</i>	<i>Date Implanted</i>	<i>Radiotag Failure</i>	<i>Radiotag Life, days</i>
1	South	5/03/79	5/09/80	362
2	South	5/03/79	10/05/79	155
3	South	5/03/79		
4	South	5/04/79	5/12/80	376
5	South	5/04/79	1/30/80	272
6	South	5/04/79	10/05/80	154
7	South	5/04/79	10/06/79	155
8	Middle	5/05/79		

(Continued)

Table 1 (Concluded)

<i>Fish No.</i>	<i>Pool</i>	<i>Date Implanted</i>	<i>Radiotag Failure</i>	<i>Radiotag Life, days</i>
9	Middle	5/05/79	8/17/79	104
10	Middle	5/05/79	12/16/79	225
11	South	8/10/79	12/10/79	122
13	South	8/10/79		
14	East	8/10/79	8/16/79	6
17	East	8/10/79	8/17/79	7
18	East	8/10/79	8/18/79	8
19	East	8/10/79	5/09/80	277
20	East	8/10/79	8/25/79	15
23	West	8/11/79		
25	West	8/11/79	1/07/80	151
26	West	8/11/79	9/26/80	414
28	South	12/18/79	4/04/80	108
29	South	12/18/79	4/04/80	108
30	South	4/08/81	5/21/81	43
31	East	12/18/79	12/10/80	350
32	West	12/18/79	9/25/80	282
33	East	12/18/79	12/10/80	350
34	West	12/18/79	3/16/81	454
60	South	4/08/81	5/26/81	48

Table 2  
Wildlife Materials Radiotag Performance Characteristics\*

<i>Fish No.</i>	<i>Pool</i>	<i>Date Implanted</i>	<i>Radiotag Failure</i>	<i>Radiotag Life, days</i>
35	East	2/19/81		
37	East	2/19/81	4/08/81	48
38	Gatlin	2/18/81		
39	East	12/18/80		
40	South	4/08/81		
41	East	12/18/80		
42	Gatlin	2/18/80		
43	East	12/18/80		
45	East	2/19/81		
46	Gatlin	2/18/80		
48	South	4/08/81		
49	East	12/18/80		
50	Gatlin	2/18/81		
51	East	12/18/80		
52	South	4/08/81		
53	South	4/08/81		
54	Gatlin	2/11/81		
56	South	4/08/81		
57	East	2/19/81		
58	South	4/08/81	5/27/81	59
59	East	2/19/81		

\* Four tags removed from dead fish were not reimplanted.

Forty-nine tagged white amur were released into Lake Conway. The first 10 fish, tagged on 2 May 1979, were released after 24 hr of observation. Two of the fish died within 11 months and the recovered tags failed before they could be reimplanted. Five tags failed within 8 months after stocking while still in the fish. Two fish released in May 1979 can still be monitored. Thirty fish were obtained in Fort Lauderdale on 7-9 August 1979 and were transported to Lake Conway for implantation and release on 10 August. Exceptional stress from capture and transportation in midsummer temperatures killed many of these fish prior to surgery. Ten tagged fish in fair condition were released. Three soon died and the tags were recovered, but two failed before they could be reimplanted. Seven tags failed while in the fish. Only one radiotag remains functioning from the August 1979 group. Six of nine fish tagged on 19 December 1979 were released on 18 January 1980. Cooler temperatures and improved surgical techniques allowed for better survival than in August. One fish was resutured, held for 1 month of observation, and released; however, the tag failed 2 months after stocking. Two more tag failures occurred in late September 1980, two in December, and two in April 1981, leaving only four radiotags purchased from the AVM Instrument Company functioning after 29 months of use.

Twenty-five white amur captured by electroshocking were tagged with Wildlife Materials, Inc., radiotags between 10 December 1980 and 8 April 1981. Two recovered AVM tags were implanted in April but failed before releasing into the lake. Four white amur with severe spinal arching were tagged to determine if this deformity, fairly common with white amur, would cause them to behave differently than the normal fish. These fish were apparently more sensitive to tagging procedures, as three died the day after implantation and the fourth recovered much more slowly than the normal fish. Cooler temperatures and longer confinement (averaging 56 days) in the holding pens resulted in a 96 percent survival rate as only 1 of 22 normal fish died. The tag in this fish lodged between the body wall and intestine and was probably the cause of death (14 days after surgery). Bidgood (1980) suggests attaching a monofilament loop to the radiotag with teflon tape and incorporating the loop in a suture while closing the incision to prevent the tag from slipping. All 22 surviving fish were completely healed when released and new scales covered the incisions.

### **Observations**

Twenty-six months of telemetry tracking data were collected from May 1979 to September 1981. Thirty amur were located more than 20 times, totaling 2090 sightings. Only one fish, No. 3, was tracked the entire period. Three other fish, Nos. 13, 23, and 26, were tracked for more than 1 year. Seasonal data were collected for the remaining 26 fish.

### **White amur behavior**

**Home range.** Most of the amur exhibited a 7- to 10-day period of movement immediately after stocking, but eventually established a home range. The fish

may have been searching for preferred vegetation and settled down once the vegetation was encountered. Five of the thirty most frequently tracked fish were released over unvegetated lake bottom deeper than 6 m. The remaining fish were released along vegetated shoreline; eight in *Nitella* and seven in *Potamogeton*, which are preferred food species, and ten in *Vallisneria*, which is nonpreferred. *Hydrilla*, the submergent macrophyte most preferred by the amur (Schardt and Nall 1980), was eliminated from Lake Conway shortly after the first tagged fish were stocked.

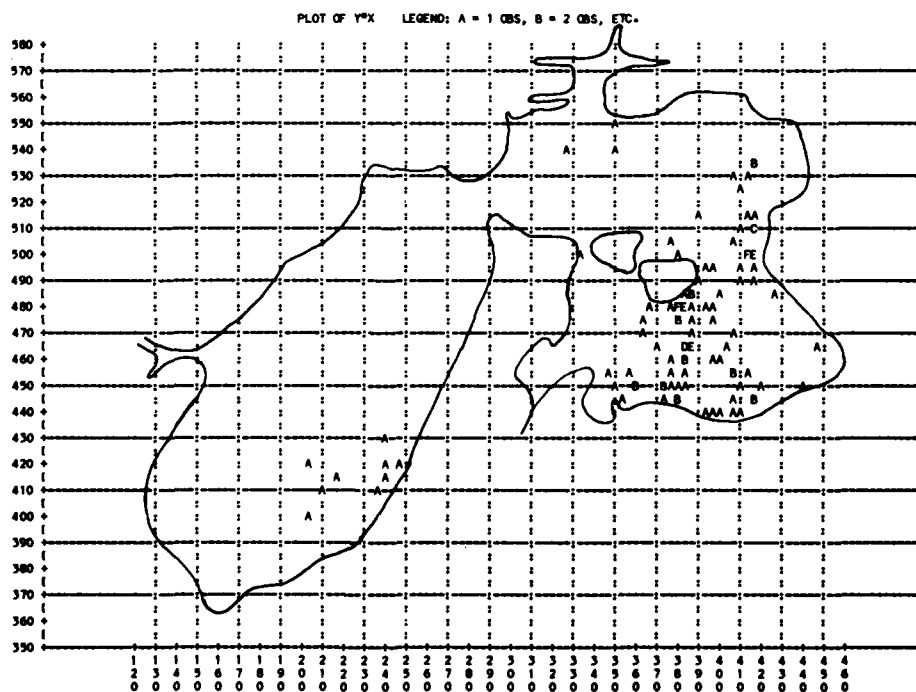
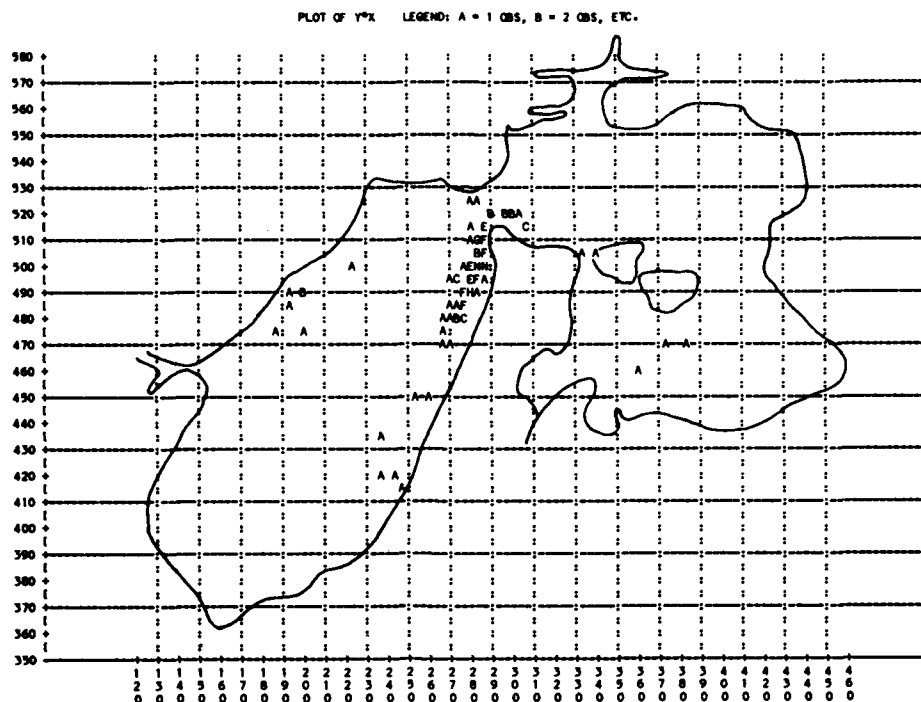
No fish remained nor established home ranges at the release sites. Once a range was established, the fish usually remained in the region until preferred vegetation was eliminated or significantly reduced. Divers observed progressive clearing of *Nitella* beds in areas inhabited by tagged fish while fecal deposits containing *Nitella* and *Potamogeton* were found in the cleared zones.

Fish No. 26 (Figure 1) is representative of 20 of 30 fish which were tracked more than 20 times. This fish was found 127 times at the junction of East and West Pools in a stand of *Nitella*, but occasionally moved as far away as 1 km. Although it was found out of its range 18 times and in preferred vegetation, No. 26 would return after a few days to the original site. Fish No. 23 (Figure 2) was located 121 times in the shallow water of East Pool in populations of *Nitella* and *Potamogeton*. Fish No. 23 moved away from its range only 17 times during the 13 months it was tracked. Fish No. 32 (Figure 3) was tracked 138 times during the 9 months which the implanted tag functioned. This fish fed in areas of *Nitella*, *Potamogeton*, and *Vallisneria* adjacent to the west shore of East Pool and wandered only 12 times.

Fish No. 34 (Figure 4) is representative of three fish that frequented more than one area. The fish crossed between East and West Pools eight times. In order to move from one range to the other, it had to cross several stands of *Nitella* and *Potamogeton*, but it did not settle in any of these areas. Fish No. 51 (Figure 5) was released 4 April 1981 in East Pool and settled in *Potamogeton* and *Vallisneria* until early March 1981, when it moved into a West Pool *Nitella* bed.

Fish Nos. 3 (Figure 6) and 13 (Figure 7) typify seven fish that did not show home ranges. Apparently, their movement was limited only by the extent of vegetation. Fish No. 3 crossed South Pool 35 times and continued the movement after *Nitella* became the only forage plant left in the lake. Fish No. 13 crossed from shore to shore in West Pool and from West Pool to East Pool stopping in populations of *Nitella* and *Potamogeton*.

**Interchange among pools.** None of the tagged fish crossed from South or East Pool into Middle Pool during the 29-month study. The shallow, narrow canals connecting these pools may have sufficiently restricted travel. The *Nitella* coverage in South Pool ranged from 28 to 58 percent (Schardt and Nall 1980) and may have provided enough food to keep the fish within the pool. Tagged fish routinely crossed between East and West Pools through the 4-m-deep and 50-m-wide channel connecting them. *Vallisneria* became the most common plant in East and West Pools (Schardt and Nall 1980) as *Nitella* and *Potamogeton* were





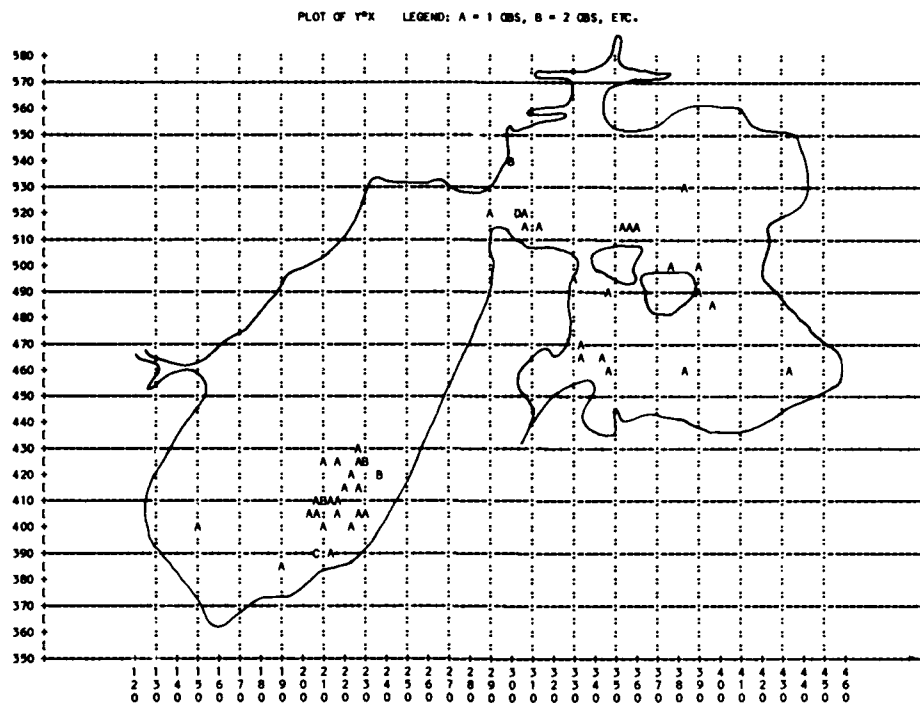


Figure 5. Plot of cumulative white amur sightings by fish for East and West Pools, fish No. 51

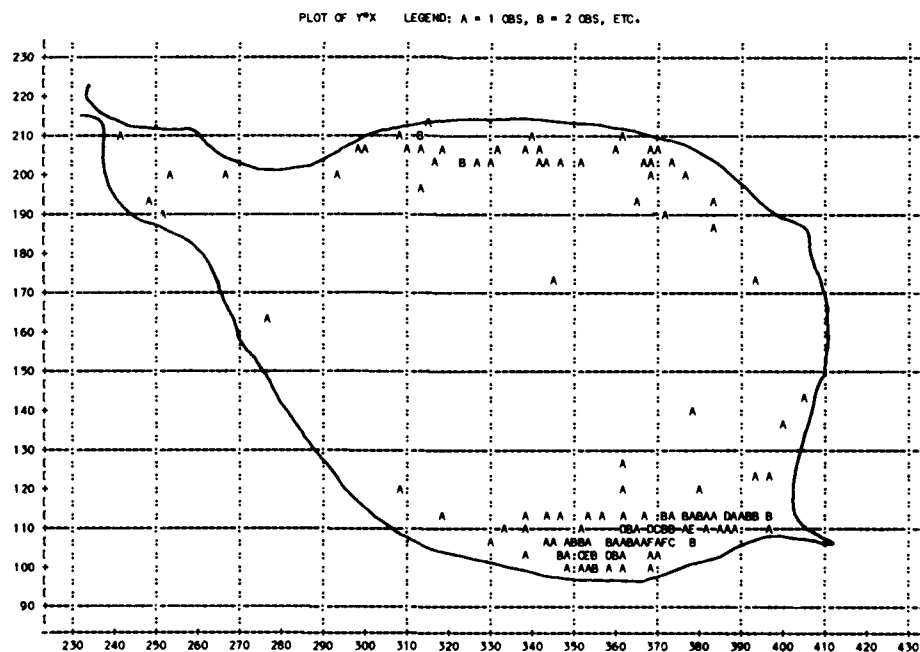
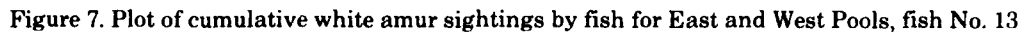


Figure 6. Plot of cumulative white amur sightings by fish for South Pool, fish No. 3



**Preference for specific areas.** Chi-square analysis revealed a specific preference ( $P>0.0001$ ) for vegetation in less than 3 m of water (Figures 8 and 9 and Table 3). Ninety-two percent of all sightings were located in vegetation (Table 4). Nonvegetated sightings approached vegetated sightings in frequency only during August and September 1980 (Table 4, Figure 10). Sixty-four percent of the nonvegetated sightings resulted from four fish: Nos. 3, 13, 23, and 34. Eighty-nine percent of the 2090 sightings (also significant at  $P>0.0001$ ) were made in water less than 3 m deep.

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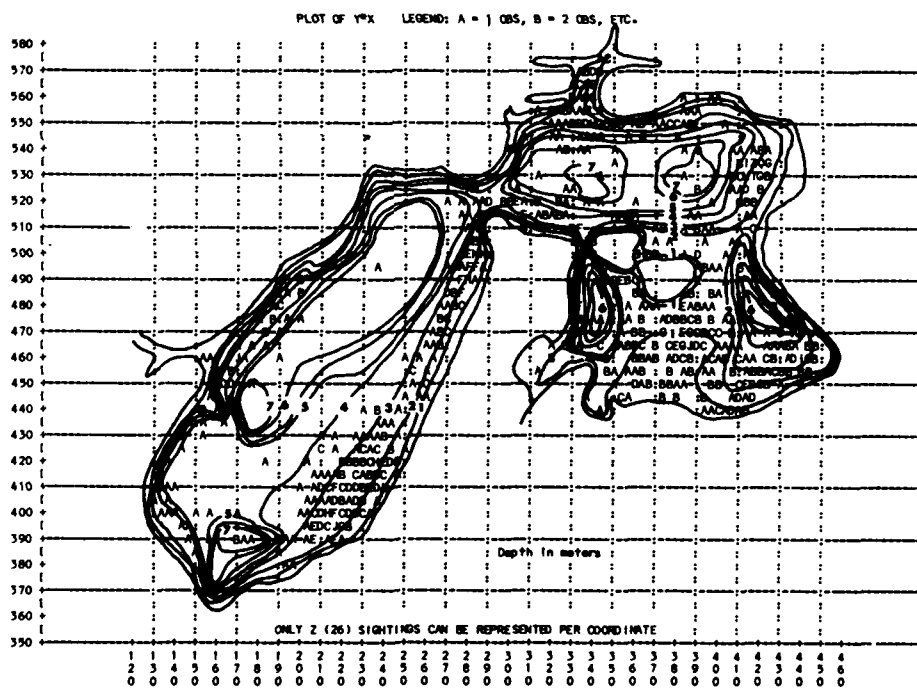
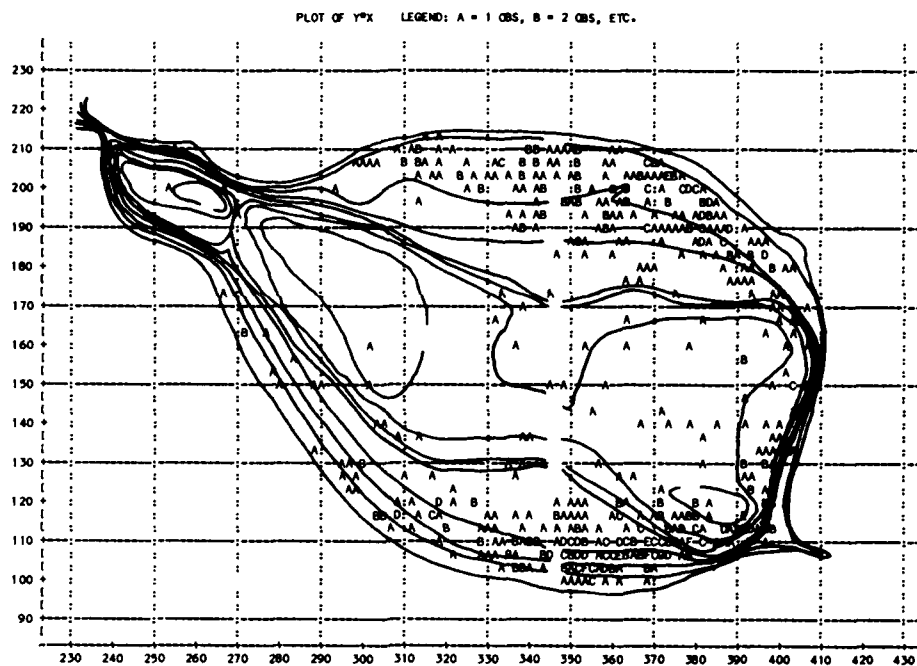


Table 3  
Individual Fish Sightings\* by Vegetated and Nonvegetated  
Areas and Water Depth  
(15 May 1979 Through 15 September 1981)

<i>Fish No.</i>	<i>Total</i>	<i>Percent Nonvegetated</i>	<i>Percent Vegetated</i>	<i>Average Water Depth, m</i>
1	29	3	97	1.79
2	26	4	96	1.88
3	191	4	96	1.81
4	90	1	99	1.79
5	77	3	97	1.88
13	158	20	80	2.65
23	138	12	88	2.32
25	40	3	97	1.68
26	145	6	94	2.22
28	44	29	71	2.91
29	51	0	100	1.90
30	141	19	81	1.91
31	93	8	92	3.01
32	138	1	99	1.99
34	136	26	74	2.38
35	34	3	97	2.35
37	26	8	92	2.88
39	55	2	98	2.16
41	49	0	100	2.24
43	62	0	100	2.21
45	28	4	96	3.07
48	24	4	96	2.63
49	62	5	95	2.15
51	56	4	96	2.48
52	26	0	100	2.27
53	23	22	78	2.74
56	26	0	100	2.62
57	28	11	89	2.57
58	59	0	100	2.08
59	35	0	100	2.80
2090				

\* Fish sighted more than 20 times are listed.

plant surveys showed that *Vallisneria*, also in the 0.5- to 3.0-m range, was unchanged or expanded as *Nitella* and *Potamogeton* were significantly reduced.

**Seasonal differences.** No seasonal differences in movement or depth were observed (Table 4, Figure 10). Fish remained in the same depths and in vegetation throughout the year. The high percentages of nonvegetated and deepwater sightings were brought about by only 5 of 30 fish and may be individual variabilities rather than seasonal behavior.

**Gregarity.** Tagged fish were often observed swimming in schools of up to 30 untagged fish. Their movement is therefore presumed to be similar to the untagged population. The possibility that so many fish would gather by chance is unlikely since preferred vegetation is still abundant in many areas of the lake. Schools containing up to three tagged fish were found on 57 occasions. On two occasions, five tagged fish were located in the same school.

**Table 4**  
**Collective Sightings by Month for Vegetated Areas and Water Depth**  
**(15 May 1979 through 15 September 1981)**

<i>Year</i>	<i>Month</i>	<i>Total</i>	<i>Percent Nonvegetated</i>	<i>Percent Vegetated</i>	<i>Average Water Depth, m</i>
1979	Jul	95	5	95	2.17
	Aug	26	15	85	2.42
	Sep	19	0	00	2.00
	Oct	40	2	98	2.18
	Nov	49	0	100	1.33
	Dec	61	0	100	1.51
1980	Jan	217	2	98	1.83
	Feb	95	2	98	2.14
	Mar	101	15	85	2.92
	Apr	109	4	96	2.01
	May	135	0	100	2.33
	Jun	94	0	100	2.70
	Jul	129	12	88	2.53
	Aug	130	38	62	2.28
	Sep	83	52	48	2.31
	Oct	93	2	98	1.66
	Nov	0			
	Dec	0			
1981	Jan	0			
	Feb	113	2	98	2.15
	Mar	81	0	100	1.88
	Apr	139	3	97	2.44
	May	54	0	100	2.50
	Jun	107	3	97	2.68
	Jul	106	8	92	2.55
	Aug	89	3	97	2.44
Total		2165	8 Avg.	92 Avg.	2.06 Avg.

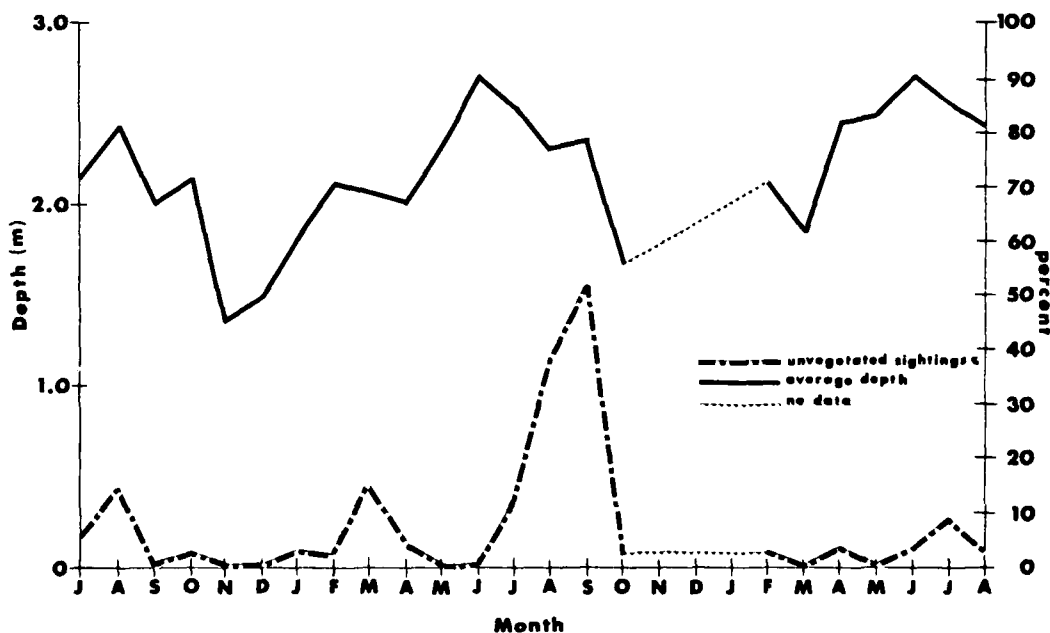


Figure 10. Average depth and percent unvegetated sightings (July 1979 through August 1981)

## REFERENCES

- Bidgood, B. F. 1980. "Field Surgical Procedure for Implantation of Radio Tags in Fish," Fisheries Research Report #20, Alberta Fish and Wildlife Division, Department of Energy and Natural Resources, Edmonton, Alberta, Canada.
- Colle, D. E., et. al. 1978. "Selective Removal of Grass Carp (*Ctenopharyngodon idella*) From an 80 Hectare Florida Lake," Preliminary Draft, University of Florida, School of Forest Resources and Conservation, Gainesville, Fla.
- Crompton, J. E., et al. 1978. "Largemouth Bass Investigations, Study VII: Investigations of Behavior, Movement and Migration Patterns of Largemouth Bass Population," Annual Performance Report, Dingell-Johnson Project F-24-11, Florida Game and Fresh Water Fish Commission, Mimeo Report, Tallahassee, Fla.
- Nall, L. E., and Schardt, J. D. 1980. Procedure for Radiotagging of White Amur for Tracking Studies," *Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma*, Miscellaneous Paper A-80-3, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 336-362.
- Schardt, J.D., and Nall, L.E. 1980. "Large-Scale Operations Management Test Using the White Amur in Lake Conway Florida; An Update on Aquatic Plant Sampling in Lake Conway After the Fourth Study Year," Unpublished paper.
- Smith, L.S., and Bell, G.R. 1967. "Anesthetic and Surgical Techniques for Pacific Salmon," *Fisheries Research Board of Canada*, Vol 24, No. 7.

# **LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA**

## **Recording Fathometer for Hydrilla Distribution and Biomass Studies**

by

Michael J. Maceina\* and Jerome V. Shireman\*

### **INTRODUCTION**

Aquatic macrophytes are an integral component of freshwater ecosystems; however, excessive amounts of vegetation can alter fish populations, limit recreational use, create health hazards, and block navigational and irrigation routes (Blackburn 1975). Hydrilla (*Hydrilla verticillata*) exists throughout 250,000 ha of Florida's water and is reported in nine other states including California (Shireman and Haller 1979). Research efforts continue to examine, formulate, and improve plant control methods, while considering positive and/or adverse impacts of these control methods on the entire aquatic system. In order to evaluate various aquatic plant control programs, quantitative data pertaining to distribution and biomass of the plant must be obtained.

Currently, white amur are being intensively investigated as a biocontrol agent of nuisance aquatic plants. Lake Baldwin was originally stocked in 1975 with 4999 fingerling white amur (12 to 150 mm total length (TL)). The chemical herbicide Hydout [Mono (N-dimethylakylamine)] was also applied to the lake to eliminate hydrilla. By the summer of 1977, hydrilla once again became a problem in the lake with coverage estimated to be 50 percent. In order to determine if sufficient white amur were present for hydrilla control, the lake was selectively treated with rotenone (Colle et al. 1978). The estimated number of white amur remaining in the lake was approximately 3 fish/ha. An additional 1845 white amur over 304 mm TL were stocked during the summer of 1978. These fish were large enough to avoid predation (Shireman, Colle, and Rottman 1978). Hydrilla was monitored from 1978 to evaluate the effectiveness of white amur in the lake.

The purpose of this research project was to continue to refine previous fathometer techniques (Maceina and Shireman 1980) and examine hydrilla abundance-white amur interactions in Lake Baldwin.

### **OBJECTIVES**

Specific objectives were to:

- a. Refine and test earlier fathometer techniques in other lakes to correlate actual plant biomass with chart-tracing characteristics.

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- b. Monitor hydrilla abundance in Lake Baldwin following white amur stocking.
- c. Determine white amur growth, condition, and food habits of the fish in Lake Baldwin.

## METHODS AND MATERIALS

A DE-719 Precision Survey Fathometer (Raytheon Marine Co., Manchester, N.H.) was utilized for all vegetation studies. Procedures for conducting transects and determining quantitative vegetation parameters were followed according to the method outlined by Maceina and Shireman (1980). Attempts were made in six lakes to correlate and develop regression models predicting hydrilla biomass by fathometer tracing characteristics.

While transects were being conducted on each lake, numbered buoys were dropped to mark hydrilla biomass sampling stations. Simultaneously, corresponding fix marks were placed on the chart paper and the buoy number was recorded on the paper. The following day, a circular core biomass vegetation sampler was used to take replicated 0.257-m<sup>2</sup> samples at each buoy. Samples collected with the biomass sampler were washed and shaken in a nylon net to remove excess sand, muck, and water and weighed to the nearest 5 g. Wet weights were later converted to kilograms per square metre for analysis.

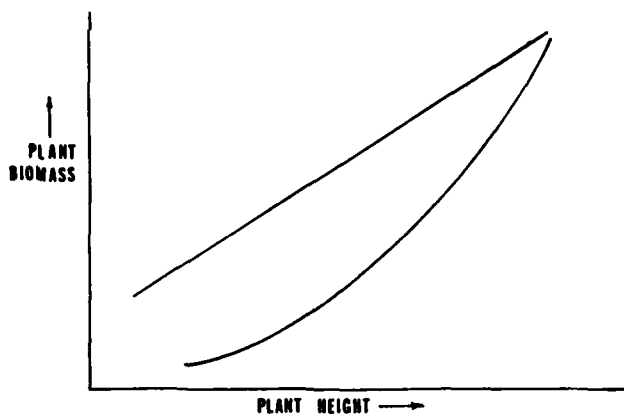
In five oligotrophic lakes located in the Florida panhandle, biomass samples of mixed stands of bladderwort (*Utricularia vulgaris*) and milfoil (*Myriophyllum pinnatum*) were taken by scuba divers. Submersed vegetation samples were designated with the recording fathometer in a similar fashion to the methods previously mentioned. Plants were washed and dominant species were noted and oven dried at 60° C for 72 hr for dry weight determinations. Weights were later converted to grams per square metre for analysis.

Hydrilla was monitored regularly in Lake Baldwin from May 1978 utilizing the recording fathometer. Total standing crop determinations were made employing previously tested fathometer tracing-biomass regression equations. White amur were captured throughout the study period utilizing direct current pulse electrofishing gear, monofilament gill nets, rotenone, and a modified gill net-seine. Fish were measured in millimetres for total length and weighed to the nearest 0.05 kg.

## RESULTS

A number of fathometer tracing characteristics were examined; however, only three, plant height, plant cover, and plant-surface distance, were used to calculate biomass. Plant height was defined as the distance from hydrosol to the top of the plant. Generally, as plant height increased, biomass also increased either in a linear or logarithmic fashion (Figure 1). Vertical percent cover was an ocular estimate of plant density. Values ranged from 1 to 100 percent. The darker and

Figure 1. General response curves for plant height as measured from chart tracings regressed against plant biomass



tighter tracing lines appeared, the closer the coverage would be to 100 percent. Lighter tracing patterns indicated sparse plant coverage and lower cover values. As the percent vertical cover increased, biomass also increased in all the lakes studied (Figure 2). This typically followed a linear or logarithmic response. The plant-surface distance was the distance from the top of the plant to the water's surface. As submersed plants approach the surface, the number of leaves on the stems increase and the growth patterns tend to become horizontal. This adds weight to the plant. Hence, tracing characteristics of plants growing in deeper water, further from the surface, were usually associated with a decline in biomass (Figure 3). This always followed a negative exponential response in the lakes examined and may be due in part to the exponential decay of light through the water column (Wetzel 1975).

Two separate models were developed for each lake which were designated "sparse" and "thick" hydrilla. "Thick" hydrilla was caused by high plant density where sound waves from the fathometer could not penetrate to the lake bottom

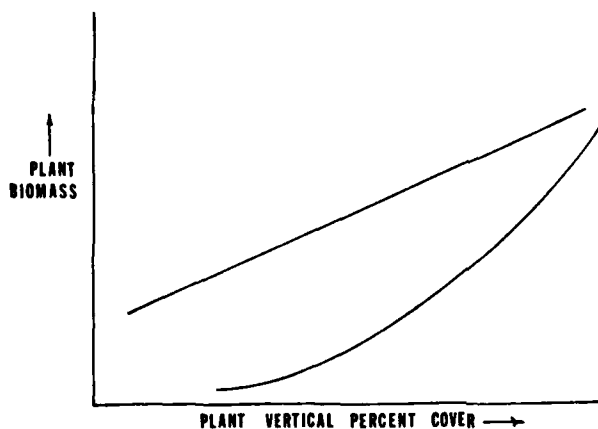


Figure 2. General response curves for plant vertical percent cover as measured from chart tracings regressed against biomass

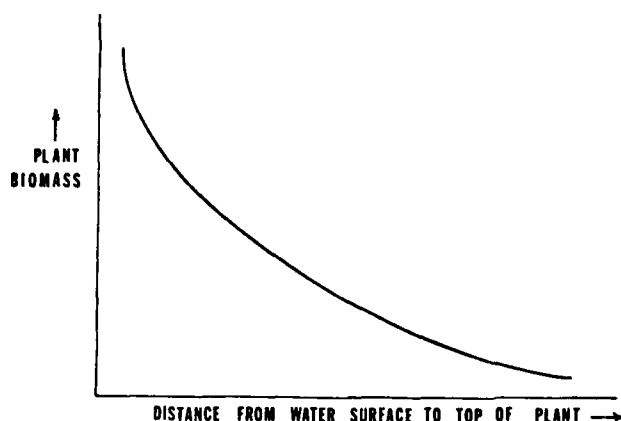


Figure 3. General response curve for plant-surface distance as measured from chart tracings regressed against biomass

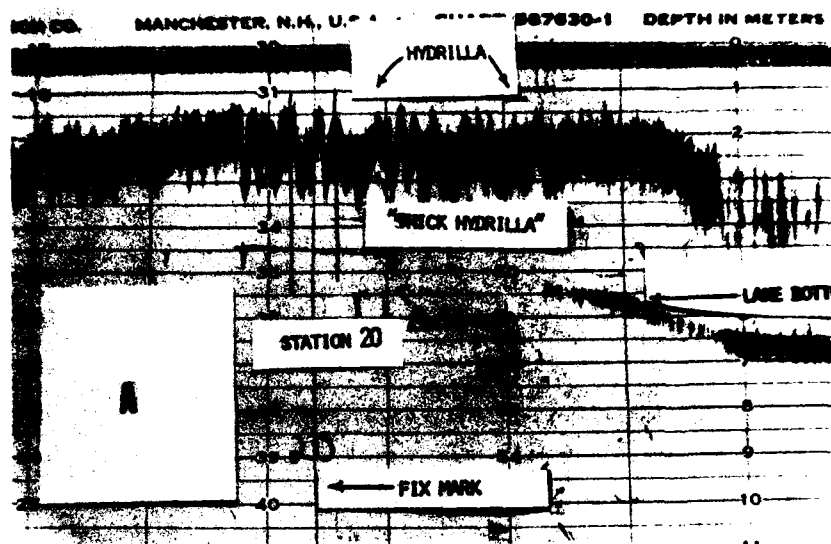
(Figure 4a). This was an area of extremely high biomass. "Sparse" hydrilla is indicated by tracing patterns in which lake bottom could be read (Figure 4b). This corresponded to lower biomass. By factoring out these two plant types, better predictions of biomass were made.

For "thick" multiple regressions, plant height and the plant-surface distance were employed in model building. In "sparse" multiple regression, plant height, plant cover, and plant-surface distance variables were entered into the analysis. Not all these variables were necessarily used to predict biomass. Variables that did not significantly increase coefficient of determination values ( $r^2$ ) and increase the F-statistic were dropped.

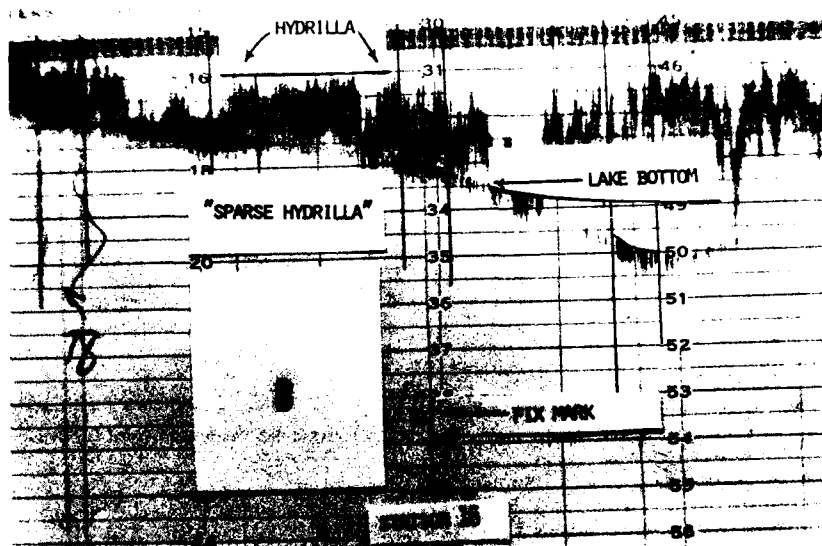
All models developed on six lakes were significant ( $P > 0.05$ ) at varying levels (Table 1). Plant tracing characteristics were able to predict biomass in a number of different lakes. The accuracy, however, of these models varied. Biomass variation explained from tracing characteristics ranged from 65 percent in Lake Baldwin down to 15 percent in Lake Pearl. Possible reasons for this include:

- a. The difference in plant growth types, densities, and forms.
- b. Substrate type differences caused variation in the efficiency of the biomass sampler to completely collect samples.
- c. The water depth sampled varied greatly among lakes. Generally, the greater the range of water depths sampled, the higher the  $r^2$  values.

During the summer of 1978, 1845 white amur over 304 mm TL and averaging 0.79 kg in weight were stocked into Lake Baldwin to monitor their effectiveness in controlling hydrilla. A population estimate in the fall of 1977 revealed 190 resident white amur remained in the lake (Colle et al. 1978). Sixty-eight smaller ( $TL \bar{x} = 390$  mm) white amur remained in the lake following the population estimate with 20 large original resident white amur stocked back into the lake in late 1977. Assuming full survival, 2123 amur completely eliminated hydrilla in Lake Baldwin less than 2 years after the 1978 stocking (Table 2). Maximum hydrilla coverage and standing crop was 62 ha and  $1.987 \times 10^6$  kg fresh weight hydrilla. The



a. Thick hydrilla



b. Sparse hydrilla

Figure 4. Sections of fathometer chart tracings

**Table 1**  
**Summary of Best Fitting**  
**Hydrilla Biomass-Fathometer Tracing Characteristics**  
**Regression Equation Success in Six Lakes**

<i>Lake</i>	<i>Type</i>	<i>Model Probability (Prob. &gt;F)</i>	<i>r<sup>2</sup></i>
Baldwin*	Sparse	>0.001	0.65
	Thick	>0.001	0.63
Stella	Sparse	>0.001	0.62
Panhandle Lakes**	Sparse	0.017	0.56
Orange	Sparse	0.006	0.47
	Thick	0.006	0.53
Kings Bay	Sparse	>0.001	0.22
	Thick	>0.001	0.23
Pearl	Thick	0.036	0.15

\* Maceina and Shireman (1980).

\*\* Biomass samples collected contained bladderwort and milfoil.

**Table 2**  
**Submersed Vegetation Data, Lake Baldwin, Florida, 1978 to 1980**

<i>Date</i>	<i>Coverage ha</i>	<i>Percent Cover</i>	<i>Volume Infestation ha-m</i>	<i>Percent Volume Infestation</i>	<i>Hydrilla Standing Crop (kg × 10<sup>3</sup>)</i>
11 May 78	45.4	57.9			
14 Jun 78	48.4	61.7	106.9	31.0	1.739
2 Aug 78	52.4	66.8	133.8	38.8	1.987
4 Nov 78	62.0	79.1	135.0	41.1	1.735
6 Jan 79	61.3	78.2	125.0	36.3	1.484
5 Mar 79	55.3	70.5	71.5	20.8	0.577
21 Jun 79	54.0	68.9	69.8	20.6	0.796
3 Aug 79	37.3	47.6	52.7	15.3	0.790
12 Sep 79	31.5	40.2	44.8	13.0	0.781
22 Dec 79	29.9	38.1	29.3	8.5	0.362
5 Mar 80	16.7	21.3	6.5	1.9	0.032
25 Jun 80	5.9*	7.5*	1.4*	0.4*	
15 Sep 80		<5**			

\* Filamentous algae, *Lyngbya* sp., dominant submersed macrophyte in Lake Baldwin replacing hydrilla.

\*\* Estimate.

successful stocking rate utilized in Lake Baldwin was 34 fish/ha of hydrilla and 1 fish per 936 kg of hydrilla.

Hydrilla control was evident by April 1979, when large areas were devoid of vegetation. Following the 1978-79 winter die-back, hydrilla standing crop increased slightly during the summer of 1979.

In April 1979 when hydrilla control was evident, white amur standing crop was estimated to be 10,000 kg, including 1978 stocked and pre-1978 stocked fish (Figure 5). Therefore, effective control was obtained with 185 kg fish/ha of hydrilla. A

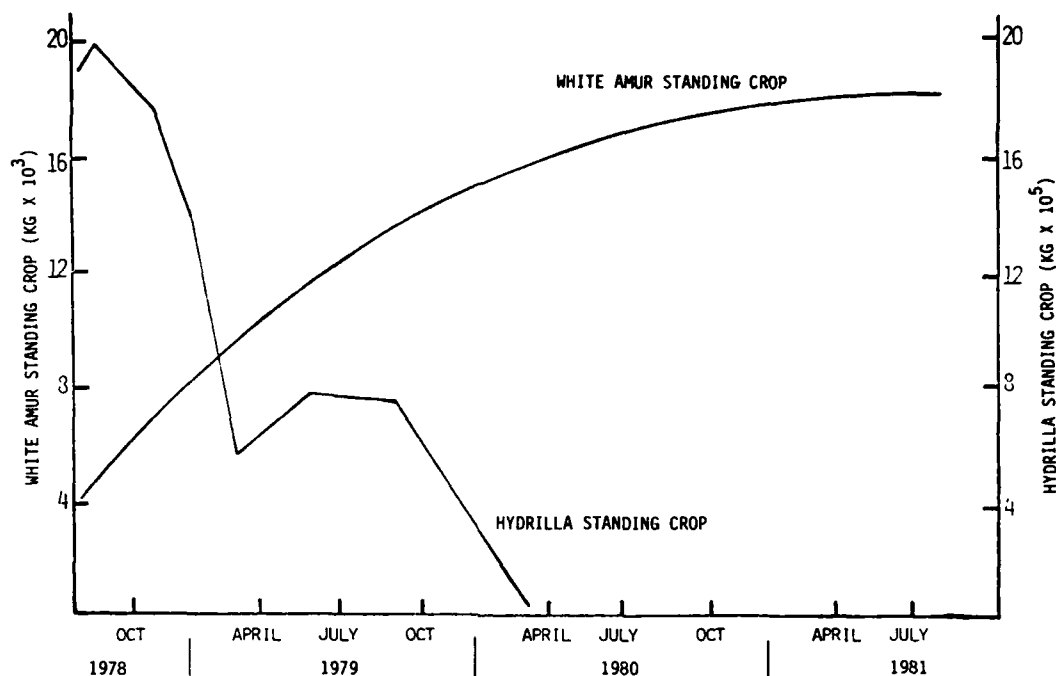


Figure 5. White amur and hydrilla standing crop in Lake Baldwin, Florida, July 1978 through July 1981

decrease in light penetration due to a phytoplankton bloom probably aided by shading hydrilla in water depths greater than 4 m during the summer of 1979. Hydrilla could not be found in the lake after March 1980.

White amur growth was rapid during the first 2 years after stocking, with fish obtaining a mean weight of 9.15 kg (Table 3). Following hydrilla removal in April 1980, white amur growth was greatly reduced. Daily weight increases from time of stocking to July 1980 averaged 10 to 12 g. After this time, growth declined 95 to 97 percent.

Based on previous growth data, 1978 stocked white amur in Lake Baldwin should have reached 13 kg 3 years after introduction; however, hydrilla removal severely curtailed growth after April 1980.

Associated with a decrease in growth was the decline of white amur condition factors [K(TL)'s] during the study period (Table 4). The K(TL)'s were highest in 1978-79 during the winter and spring months, and significantly ( $P < 0.05$ ) decreased and appeared to stabilize after the summer of 1980. Mesenteric fat was present in fish prior to and during the winter of 1979-80, and decreased during 1980-81. This probably accounted for some of the decline in K(TL)'s. Also, between July 1980 and July 1981, white amur only gained an average of 0.15 kg, but grew 41 mm, which would tend to depress K(TL)'s. The removal of hydrilla, the primary food source of white amur in the lake, caused condition factors and growth to decline.

**Table 3**  
**White Amur Growth Rates from Lake Baldwin**

	<i>Years Following Stocking</i>					
	<i>0</i> <i>(Jul 78)</i>	<i>1/2</i>	<i>1</i> <i>(Jul 79)</i>	<i>1-1/2</i>	<i>2</i> <i>(Jul 80)</i>	<i>2-1/2</i> <i>3</i> <i>(Jul 81)</i>
$\bar{x}$ weight, kg	0.79	3.00	5.25	7.25	9.15	9.25
Growth, kg		2.21	2.25	2.00	1.90	0.10
Growth, g/day		12.1	12.3	10.9	10.4	0.5
$\bar{x}$ length, mm TL	408	592	720	807	876	907
Growth, mm TL		184	128	87	69	33

**Table 4**  
**Mean K(TL), Standard Error (SE), and Number (N) of White Amur  
Collected from Lake Baldwin, 1978-1981**

	<i>Winter</i> <i>1978-79</i>	<i>Spring</i> <i>1979</i>	<i>Summer</i> <i>1979</i>	<i>Winter</i> <i>1979-80</i>	<i>Spring</i> <i>1980</i>	<i>Summer</i> <i>1980</i>	<i>Winter</i> <i>1980-81</i>	<i>Spring</i> <i>1981</i>
Both Sexes ( $\bar{x}$ )	1.58 <sup>a</sup>	1.49 <sup>ab</sup>	1.41 <sup>b</sup>	1.47 <sup>b</sup>	1.30 <sup>cd</sup>	1.25 <sup>cd</sup>	1.25 <sup>d</sup>	1.25 <sup>d</sup>
SE	0.04	0.08	0.04	0.01	0.01	0.08	0.03	0.02
N	10	5	7	90	150	2	18	28
Male ( $\bar{x}$ )	N.S.	N.S.	1.43 <sup>a</sup>	1.42 <sup>a</sup>	1.27 <sup>b</sup>	N.C.	1.22 <sup>b</sup>	1.25 <sup>b</sup>
SE	—	—	0.06	0.01	0.01	—	0.02	0.04
N	—	—	4	32	87	—	2	9
Female ( $\bar{x}$ )	N.S.	N.S.	1.39 <sup>ab</sup>	1.49 <sup>ab</sup>	1.34 <sup>b</sup>	1.25 <sup>b</sup>	1.24 <sup>b</sup>	
SE	—	—	0.07	0.03	0.03	0.08	0.03	0.02
N	—	—	3	26	62	2	16	19

NOTES: Mean values followed by the same letter are not significantly ( $P < 0.05$ ) different.

N.S. = not sexed.

N.C. = not collected.

Winter = December, January, February, March.

Spring = April, May, June.

Summer = July, August, September.

Foreguts were examined for food of white amur collected between December 1980 and June 1981 in order to determine feeding behavior of the fish once hydrilla had been removed. Forty-five gut tracts were examined and thirty-nine contained food. Panicum was observed to have the highest frequency of occurrence followed by filamentous algae, detritus, waterhyacinth roots, and cattail stems (Table 5). White amur feeding appeared to be selective towards panicum. Maximum panicum coverage in Lake Baldwin is approximately 0.1 to 0.2 ha while filamentous algae probably exceeds 2 ha in coverage. Cattail, which has the same coverage as panicum, is poorly utilized as a food source. Although panicum was a preferred food after hydrilla removal, we did not observe a decline in the amount of panicum in the lake.

**Table 5**  
**Number of Stomachs and Frequency of Occurrence of Food Items**  
**Consumed by White Amur from Lake Baldwin,**  
**December 1980 to June 1981\***

<i>Food Item</i>	<i>Number of Stomachs Containing Food Item</i>	<i>Frequency of Occurrence, %</i>
<i>Panicum hemitomen</i> and <i>P. repens</i>	24	62
Filamentous blue-green algae primarily <i>Lyngbya</i> sp.	17	44
Detritus	9	23
Waterhyacinth roots	6	15
<i>Typha latifolia</i>	2	5

\* Of the 45 foregut tracts examined, 39 contained food.

## REFERENCES

- Blackburn, R. D. 1975. "Aquatic Macrophytes and Their Problems," *Water Quality Management Through Biological Control*, P. L. Brezonik and J. L. Fox, eds, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Fla., Report No. ENV-07-75-1, pp 5-8.
- Colle, D. E., et al. 1978. "Utilization of Selective Removal of Grass Carp (*Ctenopharyngodon idella*) From an 80-hectare Florida Lake to Obtain a Population Estimate," *Transactions of the American Fisheries Society*, Vol 107, pp 724-729.
- Maceina, M. J., and Shireman, J. V. 1980. "The Use of a Recording Fathometer for Determination of Distribution and Biomass of Hydrilla," *Journal of Aquatic Plant Management*, Vol 18, pp 34-39.
- Shireman, J. V., Colle, D. E., and Rottmann, R. W. 1978. "Size Limits to Predation on Grass Carp by Largemouth Bass," *Transactions of the American Fisheries Society*, Vol 107, pp 213-215.
- Shireman, J. V., and Haller, W. T. 1979. "The Ecological Impact of Integrated Chemical and Biological Aquatic Weed Control," Annual Report submitted to the U.S. Environmental Protection Agency.
- Wetzel, R. G. 1975. *Limnology*, W. B. Saunders Co., Philadelphia, Pa.

# **LARGE-SCALE OPERATIONS MANAGEMENT TEST OF PREVENTION METHODOLOGIES: MILFOIL FRAGMENT AND DIVER DREDGE STUDIES**

by  
K. Jack Killgore\*

## **BACKGROUND**

The U.S. Army Engineer Waterways Experiment Station (WES), in cooperation with the Seattle District (NPS), is evaluating the concept of prevention as an operational technique for managing Eurasian watermilfoil, or milfoil (*Myriophyllum spicatum* L.), in the State of Washington. Prevention is defined as any activity undertaken to keep a population of a problem aquatic plant species from reaching a level that interferes with users' interests in a water body (e.g., irrigation, navigation, recreation). A prevention program must simultaneously acknowledge the improbability of completely stopping the target species from reaching a previously uncolonized water body and the probability that early detection and subsequent treatment can prevent the population from attaining problem levels. In 1979, a Large-Scale Operations Management Test (LSOMT) was initiated to evaluate this prevention concept. This report summarizes the results of two studies that formed part of the entire FY 81 research. One study evaluated the sinking rates and survivorship of vegetative fragments of milfoil. The second study evaluated the feasibility of using a diver-operated dredge to remove colonizing populations of milfoil.

## **MILFOIL FRAGMENT STUDY**

Milfoil apparently was introduced from Europe into North America in the 19th century. The plants can disperse rapidly by vegetative fragmentation. Profuse growth of newly established populations in a water body can exclude existing populations of native species and interfere with the economic, recreational, and aesthetical aspects of the drainage system it colonizes.

Milfoil apparently was introduced in the Okanogan River, British Columbia, in the 1970's and had spread into the Columbia River by 1981 (Figure 1). Although milfoil is distributed sparsely among native aquatic plants in the Columbia River, unchecked growth could restrict use of this river. In order to better understand the magnitude of milfoil's dispersal and reproductive ability in a lotic habitat, a milfoil fragment study was conducted in September 1981, in the Okanogan River, Washington.

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\* U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

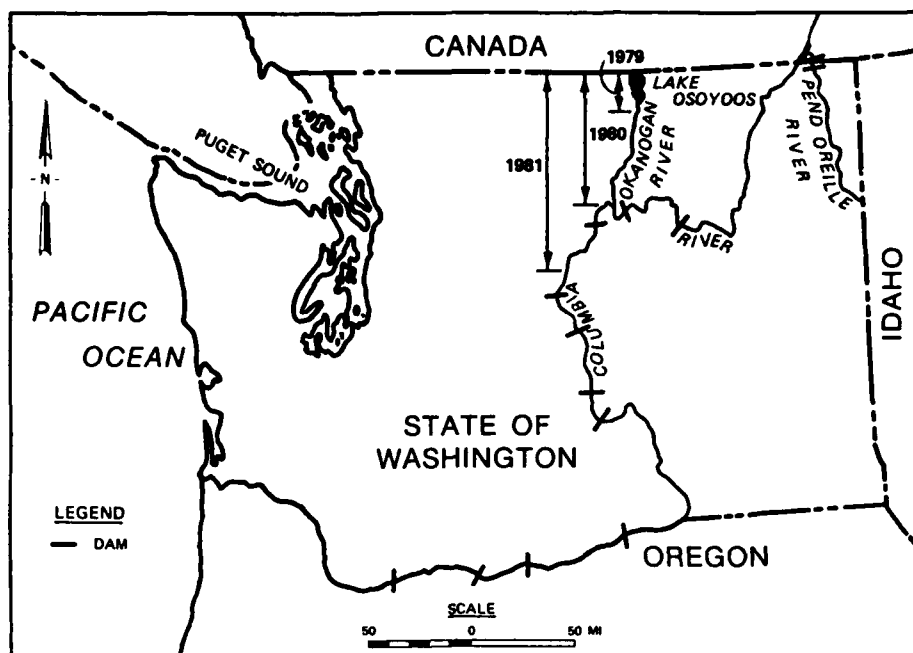


Figure 1. Eurasian watermilfoil's rate of spread in the Columbia River drainage system, 1979-1981

### Objectives

The objectives of the 1981 milfoil fragment study were to: (1) determine milfoil fragment floating time by size class, and (2) evaluate milfoil fragment viability by determining rooting success upon sinking.

### Materials and methods

Four individual 1.2- by 1.2-m containments were constructed of 2-cm mesh fiberglass screen and placed in typical milfoil habitat in the Okanogan River. Forty milfoil fragments of four size classes (5, 15, 25, and 35 cm) were cut from existing milfoil populations. The 160 fragments were measured distally from the apical tip of a stem, cut, and placed into one of the four containments. Each containment received 40 fragments of a single size class. The fragments were submerged in water during all collecting and placement activities. Although naturally produced fragments will vary in length, the four selected size classes represent fragment lengths that have been observed in the Okanogan River. Water quality measurements were recorded before, midway through, and just after the study. Parameters estimated were temperature, dissolved oxygen, conductivity, water velocity, and photosynthetically active radiation. Daily counts were taken of the number of floating fragments of each size class. At the end of the 18-day study, both sunken and floating fragments were inspected for the presence of adventitious roots. Sunken fragments with roots were inspected more closely to see if they had rooted to the substrate.

## Results

Autofragmentation occurred in size classes 15, 25, and 35 cm, resulting in a total of 14 additional fragments of these sizes at the end of the study. Three fragments in the 5-cm size class were lost apparently by flowing out small gaps that periodically developed at the hydrosol-containment wall interface. Most fragments became loosely encrusted with marl and periphyton within 10 days after placement in the containments. All fragments appeared green and healthy after being washed at the end of the study.

The results of the water quality measurements are summarized below:

Water Quality Indicator	Day		
	0	13	21
Temperature, °C	16.3	15.9	14.2
Conductivity, mhos/cm	164	164	158
Dissolved oxygen, mg/l	8.7	10.7	8.0
pH	8.1	8.1	7.8
Photosynthetically active radiation, lux			
Air	6000	5200	5600
Water	3500	3500	3700
Water velocity, cm/sec	3.0	0	0
Depth, m	1.2	1	1
Time, 2400-hr clock	1300	1400	1200

Water quality indicators remained relatively constant throughout the study. Water velocity inside the containments decreased from 1.0 to 0.0 ft/sec due to algae covering the mesh screen.

Sinking rates for the four size classes of fragments are presented in Figure 2. The sinking rates observed were inversely proportionate to fragment length

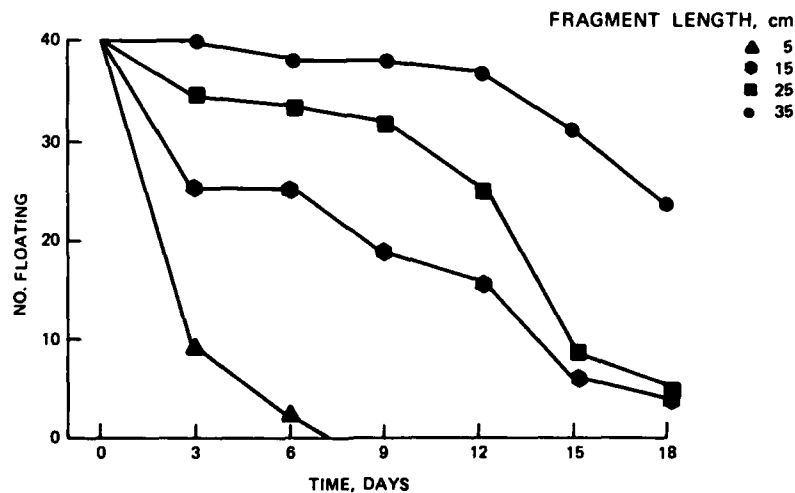


Figure 2. Eurasian watermilfoil sinking rate, 1981

throughout the 18 days of observations. The number of floating fragments at the end of the study were: 5 cm—0; 15 cm—4; 25 cm—4; 35 cm—23. All of the 5-cm fragments had sunk by day 7, whereas only 2 of the 35-cm fragments had sunk by the same date.

Figure 3 shows the conditions of the fragments at the end of the study. Percentage of fragments firmly rooted to the substrate at the end of the study were: 5 cm—72.5 percent; 15 cm—47.5 percent, 25 cm—47.5 percent, 35 cm—22.5 percent. These differences in number of fragments attached to the hydrosol probably reflect the different sinking rates and not different rates of root penetration once fragments have sunk. Out of a total of 171 fragments observed at the end of this study, only one fragment in the 5-cm size class had not formed adventitious roots. All roots developed at the nodes and only two roots per node were formed.

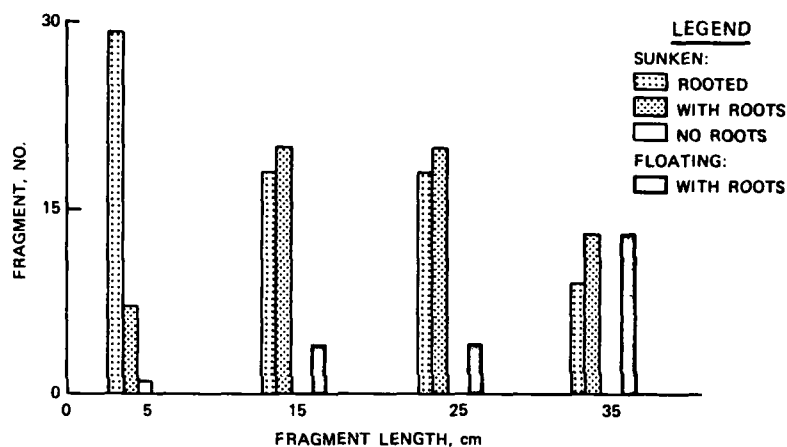


Figure 3. Fragment condition at the end of the Eurasian watermilfoil fragment viability study, 1981

## Discussion

Milfoil can reproduce via asexual vegetative fragmentation or sexual seed production. Viable seeds produced sexually provide for long distance dispersal and may prevent local extinctions (Smith 1963). These seeds also enhance long-term fitness by providing new genotypes for selection to act upon. Vegetative fragments are the most important means of dispersal within a body of water or between closely adjacent water bodies (Patten 1956; Smith, Hall, and Stanley 1967; Coffey and McNabb 1974; Grace and Wetzel 1978). Fragmentation also provides for rapid buildup of populations that recently have colonized new habitats. Despite the importance of vegetative fragmentation to milfoil's ability to disperse to and heavily infest new habitats, few studies have dealt with fragment ecology.

Results of this experimental study of milfoil fragments in the Okanogan River suggest that fragments can travel through lotic systems for weeks and still remain viable. The period of time that fragments remain floating is proportionate to their

length. Apparently, disruption of the air lacunae in milfoil stems (see Grace and Wetzel (1978) for a discussion of these lacunae) sufficient to cause loss of buoyancy occurs faster in shorter fragments. Larger fragments (25 and 35 cm) often exhibit necrosis of distal segments prior to sinking. However, the apical portions of these longer fragments remain viable after necrosis of adjacent tissues occurs. These observations were made of fragments cut from plant stems in the late summer, when milfoil in the Okanogan River was beginning to die back. Natural fragmentation of milfoil plants may involve necrosis of all except the apical-most segments of stems. These apical stem portions then become vegetative "offspring" that are released to the surrounding environment after sufficient necrosis of distal tissues attaching them to the parent plants has occurred. Thus, end of growing season senescence may be used to produce numerous asexual propagules. In this experimental study, necrosis of 5- and 15-cm apical fragments was not apparent, while 82 percent of both 25- and 35-cm apical fragments exhibited necrosis of distal segments.

This study also shows that most fragments develop adventitious roots at the nodes soon after being cut from parent plants. Smith, Hall, and Stanley (1967) and Grace and Wetzel (1978) have reported similar observations. Upon sinking, the fragments anchor themselves to the substrate with these adventitious roots. In this experimental study, all but 1 of 171 fragments developed adventitious roots. Variable sinking rates, rapid root formation, and high survivorship of apical fragments observed in this study are consistent with the hypothesis that vegetative fragments are responsible for both dispersal of milfoil to closely adjacent habitats and rapid buildup of new populations. More extensive studies of milfoil fragment ecology are needed so that control programs can be planned in light of knowledge of this important dispersal mechanism.

### DIVER-OPERATED DREDGE

Various methods have been developed and used to control problem aquatic plants. The objective of most control strategies is to reduce the population level of a target species so that water body uses are not severely restricted. In comparison, the purpose of a prevention strategy is to keep a newly establishing population of a target species below a zero problem level. This may require extremely effective but costly methods. Prevention treatments must provide a maximum biomass reduction to avoid extensive control efforts that would become required for a rapidly increasing acreage of the problem species. A diver-operated dredge can be a feasible prevention type treatment because it removes the entire plant, including the roots.

Milfoil is represented sparsely in the overall aquatic plant community in the Columbia River. Because of its sparse representation among more dominant plants, nonselective treatments (e.g., chemicals and harvesters) may severely impact nontarget species. In addition, most treatment methods provide only temporary control and partial removal of the target species. As part of the LSOMT,

a diver-operated dredge (DOD) was evaluated because it can completely and selectively remove milfoil.

### Objectives

The objectives of the DOD evaluation were to determine rate of harvest and cost per acre.

### Method

The DOD used in this demonstration research was borrowed from the Canadian Ministry of Environment. This DOD was based on a 3.7- by 6.7-m pontoon barge weighing 1450 kg. Onboard equipment consisted of a Ford industrial gas engine (1198 cm<sup>3</sup>) which powered an Allis-Chalmers pump capable of pumping 22 l/sec. Suction of 63 l/sec was created by a Venturi manifold. Two 10-cm-diam suction hoses could be extended from the barge to the dredging site by divers supplied with air from onboard compressors. The divers carefully dislodged the roots so that entire plants could be directed through the suction hoses to a wire mesh spoils collection basket on the barge. Spoils were then off-loaded to a suitable disposal site.

Seven square to rectangular plots, each measuring 250 m<sup>2</sup>, were marked in areas of the Okanogan River having different milfoil densities. All milfoil beds were in sandy substrates (less than 5 percent silts and clays). To assess removal rates, measurements were made of diving hours required to remove all milfoil from each plot. Wet weight estimates of milfoil removed were made. Also, time elapsed during daily mobilization, demobilization, and equipment malfunction was measured. Potential degradation of water quality was monitored by measuring pH, conductivity, dissolved oxygen, and temperature at middepth in each plot before, during, and after dredging. Photosynthetically active radiation (PAR) was measured at the same depths and times in areas variable distances downstream of the divers and dredge. PAR measurements were made in areas without plants. PAR just above the water surface was measured concurrently with all subsurface measurements.

### Results

Photosynthetically active radiation was the only water quality indicator affected by dredging operations. PAR at middepth in downstream areas averaged 53.5 percent of PAR just above the surface prior to dredging. During dredging, middepth PAR immediately downstream of the divers was 45.7 of above surface PAR. Just downstream of the dredge outflows, middepth PAR was 25.9 percent of above surface PAR. Approximately 100 ft downstream of the dredge, middepth PAR was 53.2 percent of above surface PAR.

Diver dredge harvesting rates are summarized in Figure 4. Extrapolated to a per acre value, diving time required to remove milfoil from the seven 250-m<sup>2</sup> plots ranged from 67 to 217 hr. This time is spent by each of two divers who are in the water operating the two suction hoses. For removal of milfoil from these sandy

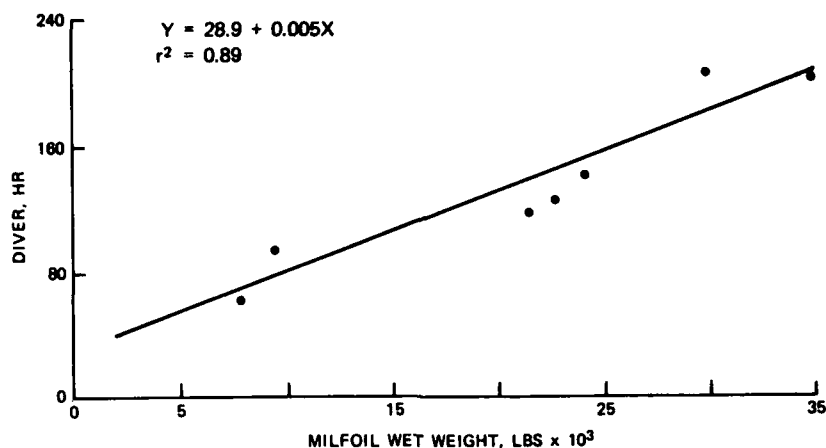


Figure 4. Diver dredge harvesting time per acre

substrates, required diving time was directly proportionate to the wet weight of milfoil in each plot. Nondiving time, including daily mobilization, demobilization, and downtime due to equipment malfunctions, has not been included in the rates shown in Figure 4. These daily nondiving hours generally totaled less than 10 percent of the daily diving hours.

### Discussion

The DOD proved to be an effective means of removing the entire plant. Intact plants were removed consistently throughout these demonstration studies. By completely removing the roots, regrowth will not occur. *Postdredging fathometer* transects over the treated plots supported these observations of complete biomass removal. However, the Canadian Ministry of Environment, in earlier studies, observed intact plants completely missed by the divers, firmly embedded roots without stems, and vegetative fragments with adventitious roots after the dredging operation (see B.C., WIB 1980). A certain advantage of using a DOD with trained divers is that the divers can provide species specific removal.

Although a DOD can operate in different types of substrates, substrate type should be considered before dredging operations are initiated. Canadian studies reported that silty substrates become extremely turbid during diving activities, creating zero visibility for the divers (B.C., WIB 1980). As a result, incomplete removal of the target species is likely. However, coarse substrates such as gravel or sand create less turbidity, but roots are difficult to remove from highly compacted sands and gravels. The present dredging operations took place in a sandy silt substrate where the roots were embedded 6 to 8 in. The divers in this study were effective at removing entire root systems, but had to dig into the soil with a tool by hand until roots dislodged. Completeness of root removal is probably a function of divers' dedication to the task and familiarity with using the suction hoses.

A DOD is more time-consuming than most other mechanical or herbicide

treatments. DOD use is recommended for removing small populations of the target species when the main objective is to virtually eradicate roots and shoots of these populations. Removal of milfoil from sandy substrates by dredging required from 67 to 217 hr/acre depending on plant density. Diving hours required to remove the plant biomass can be translated into cost/acre. While the per unit area cost of DOD treatment used in prevention strategies can be high, the avoidance of accumulating costs of potentially required control treatments may make DOD treatment cost-effective.

## REFERENCES

- B.C., WIB (British Columbia Ministry of the Environment, Water Investigations Branch). 1980. "British Columbia Aquatic Plant Management Program, Studies on Aquatic Macrophytes," Part XV, Victoria, B.C., Canada.
- Coffey, B. T., and McNabb, C. D. 1974. "Eurasian Watermilfoil in Michigan," *The Michigan Botanist*, Vol 13, pp 159-165.
- Grace, J. B., and Wetzel, R. G. 1978. "The Production Biology of Eurasian Watermilfoil (*Myriophyllum spicatum* L.): A Review," *Journal of Aquatic Plant Management*, Vol 16, pp 1-11.
- Patten, B. C. 1956. "Notes on the Biology of *Myriophyllum spicatum* L. in a New Jersey Lake," *Bull. Torr. Bot. Club*, Vol 83, pp 5-18.
- Smith, G. E. 1963. "Control of Eurasian Watermilfoil in TVA Reservoirs," *Proceedings of Southeastern Weed Control Conference*, Vol 16, pp 351-353.
- Smith, G. E., Hall, T. F., and Stanley, R. A. 1967. "Eurasian Watermilfoil in the Tennessee Valley," *Weeds*, Vol 15, pp 95-98.

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1981. -- Vicksburg, Miss. : U.S. Army Engineer Waterways  
Experiment Station ; Springfield, Va. : available from  
NTIS, 1982.  
xiv, 265 p. : ill. ; 27 cm. -- (Miscellaneous  
paper ; A-82-3)  
Cover title.  
"June 1982."  
Final report.  
"Prepared for Office, Chief of Engineers, U.S. Army."  
Bibliography: p. 265.

1. Aquatic plants. 2. Aquatic weeds. 3. Research.  
4. Weed control. I. United States. Army. Corps of  
Engineers. Office of the Chief of Engineers. II. U.S.

Annual Meeting of the U.S. Army Corps of Engineers : ... 1982.  
(Card 2)

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Laboratory. III. Series: Miscellaneous paper (U.S.  
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